NATIONAL TECHNICAL UNIVERSITY OF UKRAINE

“IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE”

Institute of Energy Saving and Energy Management

Power Supply Department

Level of education: second (Master’s), educational and professional program

Specialty: 141 "Electric power, Electrical engineering and Electromechanics"

Specialization: "Electricity supply systems for consumers"

“APPROVED”

Head of the Department

__________ Vladimir POPOV

“___” _____________ 2020

TASK

for a student's master's thesis

Rybii Mykhailo

1. Dissertation topic « *Multi-agent control in local power supply systems with flexible generation and active electricity consumers* »

supervisor of the dissertation: Denysiuk Serhii Prof., Doc. of T. Sciences.

Approved by the order of the University of "03" November 2020 №3198-р.

2. The deadline for students to submit a dissertation is December 9, 2020.
3. Object of research: Proces of functioning of local power supply systems with complex hierarchical management. Development and definition of algorithms for optimal functioning of local systems with flexible generation and active consumers.
4. Subject of research (Initial data - for a master's dissertation on the educational-professional program): Modes of operation of local energy systems within the liberalized local energy markets and oriented approach according to the Smart Grid concept regarding the choice of optimization of optimal consumption due to an individual consumption algorithm for each technological object.
5. List of tasks to be developed: Conduct a literary review of scientific publications in accordance with the defined scientific direction using a library with open access to modern scientific databases. To form a model of a local system that contains the interaction between agents, and to solve the problem of building an aggregator. The interaction of several sources of flexible generation, to assess the possible occurrence of modes of operation of several installations operating

simultaneously. Analyze the issues of electromagnetic compatibility in order to eliminate power surges, possible overloads of power lines, stability and quality of electricity, power supply and evaluation of processes between agents of local networks. To develop adapted methods and algorithms for MAS, which will be implemented in systems with flexible generation and active consumers. Organizational and technical methods of management of local systems on the basis of MAS, to develop algorithms of an estimation of perspective development of system from the point of view of multivariate and multiplicity of criteria. To optimize organizational and technical processes in systems of complex hierarchical management in modern technical and economic conditions.

6. List of graphic (illustrative) material: presentation - visual materials based on the results of the research (calculation algorithms and diagrams.

7. Publications: Rybii Mykhailo. Multi-agent management, development, determination of algorithms for optimal functioning of consumption in local systems with flexible generation and active consumers/Scientific and technical conference (based on the results of dissertation research of undergraduates). [Electronic resource]. URL:https://www.iee.kpi.ua/Scientific and technical conference of IEE undergraduates (based on the results of dissertation research of undergraduates).

Rybii Mykhailo, Boyko Ivan. Application of prosumers at the local level of smart grid and taking into account of the dynamic tarification algorithm. [Electronic resource]. URL:https://www.me.gov.ua/-24,11,2020.

Denysiuk Sergii, Rybii Mykhailo. Formation of component optimization procedures in energy systems with flexible generation and active energy consumers/"Scientific Notes of Tavriya National University named after VI Vernadsky. Series: Technical Sciences". Part 31 (70) No. 3, 2020. [Electronic resource]. URL:https://www.me.gov.ua/№10-13-86 AC 18,09,2020.

Rybii Mykhailo. Prosumers in the socio-technical field of Smart Grid. [Electronic resource]. URL:https://www.iee.kpi.ua/Scientific and technical conference of KPI masters.

8. Dissertation section consultants of normocontrol: *Prokopenko I. D.*

9. The date of issuance of the task is May 31, 2019

NATIONAL TECHNICAL UNIVERSITY OF UKRAINE

"Igor Sikorsky KYIV POLYTECHNICAL INSTITUTE"

Institute of Energy Saving and Energy Management

Power Supply Department

"On the rights of the manuscript"

UDC ______________

"Accepted to the defence"

Head of the Department

__________Vladimir Popov

"___" _____________ 2020

Master's thesis

Under the speciality: 141 Electric power, Electrical Engineering and Electromechanics

Educational and Professional Program: Energy Management and Energy Efficient Technologies

on the topic: "Multi-agent control in local power supply systems with flexible generation and active electricity consumers"

Completed by: Rybii Mykhailo, Master student (2d year), group OE-91мп

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(Signature)

Research Advisor: Prof. Doc. of T. Sciences, Denysiuk Serhii

(Scientific degree, academic title, full name)

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(Signature)

Reviewer: Professor Konrad Świrski_____

(Scientific degree, academic title, full name)

____

(Signature)

I declare that this Master's thesis does not include any borrowings from the works of other authors without corresponding references.

Student _____________

(Signature)

Kyiv, 2020

Individual plan of research of master's work Rybii Mikhailo

№ з/п	Name of stages of execution master thesis	Deadline for stages master's thesis	Note
1	Review of literature sources on the topic of the work	01.09.2020 - 30.09.2020	
2	Formation of the purpose and tasks of research	01.10.2020 - 10.10.2020	
3	Analysis of the peculiarities of the functioning of local power supply systems with flexible generation and active consumers (prosumers), the peculiarities of the functioning of the MAS at the local level.	11.10.2020 - 31.10.2020	
4	Construction of the MAS model on neural networks and operation in local Smart Grid systems.	05.11.2020 - 15.11.2020	
5	Definition of consumption algorithms and optimal functioning of local systems with flexible generation and active consumers.	20.11.2020 - 28.11.2020	
6	Development of Startup model	28.11.2020 - 03.12.2020	
7	Registration of the master's dissertation and additional materials	03.12.2020 - 09.12.2020	

Professor of Power Supply　　　　Denysiuk Serhii

Magister　　　　Rybii Mykhailo

ABSTRACT FOR MASTER'S DISSERTATION

Student: Rybii Mykhailo

Performed on the topic: "Multi-agent control in local power supply systems with flexible generation and active electricity consumers"

Specialty: 141 "Electric power, electrical engineering and electromechanics"

Specialization: "Electricity supply systems"

Structure and scope of work

The master's The master’s thesis: "Multi-agent control in local power supply systems with flexible generation and active electricity consumers". Consists of the introduction, 4 chapters, conclusions, list of used sources. The total of all work - is 114 pages of the main text, including 61 figures, 16 tables, 30 bibliographic titles in the list of references.

Relevance and description of the problem

An important problem is the unpredictability of the dispersed generation units as the main element. Modes are determined by metrological conditions, as well as the complexity of managing the processes of interaction of active consumers with the elements of the power system. There are new problems, first of all the deterioration of the situation in the power system and the emergence of such negative consequences as: deterioration of electricity supply, imbalance in the cross sections of the power system, the presence of significant reverse overload in local networks, which can become unmanageable.

Thus, there is a problem of interaction of management with the power system of a new "player" in the local electricity market as an active consumer. To do this, it is necessary to form and address optimization processes, active interaction of electricity consumers with the power system while maintaining the total benefit of the active consumer from optimizing their own schedule of electricity consumption and possible income from electricity sales with normal operation of the system.

Also, changing the traditional behavior of consumers to active needs in Ukraine to solve a number of problems. This is due to the fact that Ukraine's energy system as a whole is centralized, with high-capacity power plants, focused on classic traditional electricity consumers. They need to reconsider the participation of active consumers in creating a service system for the energy system, system integration into the network, both the most active consumers and sources of dispersed generation, or their combination as part of the MAS with the subsequent formation of units that integrate individual functions.

These problems can be solved by creating a problem-oriented multi-agent management system in local power supply systems, which allows the agency level to distribute the responsibilities of consumers in the electricity market, optimize their interaction with bilateral electricity flows to improve electricity quality, power supply quality and reliability stable operation of the power system.

Development and improvement of methods for integration of distributed generation sources into the power supply network within the problem of increasing the efficiency of flexible generation, improving the efficiency of distributed generation, creating a multi-agent control system using the potential of active consumers to optimize energy consumption and energy efficiency in local power systems. in general, it is an urgent scientific and technical task.

Purpose of research

Creation of scientific and applied bases of the organization of the local market of the electric power by development of theoretical bases, development of models, methods and means which provide the effective organization and interaction of elements of the market. Review new, additional issues that involve the use of prosumers at the local Smart Grid level.

Research method

The master's thesis is based on such a method as the Scientific research. Data and formulas were collected for further processing into a more specific answer to the question of a multiagen system. The question of the method of neural networks, which is a component of the multiagent system, is considered. Data on optimal energy consumption are considered and collected.

Object of research

Proces of functioning of local power supply systems with complex hierarchical management. Development and definition of algorithms for optimal functioning of local systems with flexible generation and active consumers. Development of visual graphs of electric load consumption, mathematical model, algorithms of optimal actions. Construction of the MAS model on neural networks and operation in local Smart Grid systems.

Subject of research

Modes of operation of local energy systems within the liberalized local energy markets and oriented approach according to the Smart Grid concept regarding the choice of optimization of optimal consumption due to an individual consumption algorithm for each technological object.

Scientific novelty

Based on my publications, some of the shortcomings in the modern power system have been identified. The scientific novelty is the optimization of the modern energy system based on multi-agent management (Smart grid). Apply a modern-modernized and scientific-technical method of neural networks for the optimal algorithm of energy consumption. Use generation as the best way to adjust power load schedules. Give examples of solving the problem of optimal energy consumption for technological processes and the system itself.

Development of a visual model of interaction between the main equipment of the active consumer, flexible generation, as well as the interaction between the active consumer and the power supply network.

Creation of a methodology for assessing the functioning of individual active consumer equipment in local power supply systems, and in the presence of flexible generation sources in general.

Improve the way of optimizing the mode of operation for specific types to get the maximum benefit for participants and choose their most effective modes of operation.

Research tasks

1. Conduct a literary review of scientific publications in accordance with the defined scientific direction using a library with open access to modern scientific databases.
2. To form a model of a local system that contains the interaction between agents, and to solve the problem of building an aggregator.
3. The interaction of several sources of flexible generation, to assess the possible occurrence of modes of operation of several installations operating simultaneously.
4. Analyze the issues of electromagnetic compatibility in order to eliminate power surges, possible overloads of power lines, stability and quality of electricity, power supply and evaluation of processes between agents of local networks.
5. To develop adapted methods and algorithms for MAS, which will be implemented in systems with flexible generation and active consumers. Organizational and technical methods of management of local systems on the basis of MAS, to develop algorithms of an estimation of perspective development of system from the point of view of multivariate and multiplicity of criteria.
6. To optimize organizational and technical processes in systems of complex hierarchical management in modern technical and economic conditions.
7. Consider optimizing a multi-agent network. the relationship between the neural network method and multiagent control. Algorithm for selecting optimal consumption using the neural network method. Give an example of a multi-agent system and a generation system for the optimal choice of electricity consumption. Illustration of visual diagrams, graphs, drawings.

Expected results of the study

Development of methods for flexible generation sources in local power systems, methods for determining the potential of the active consumer (AC) and based on algorithms for selecting the mode of operation.

Solving the optimization problem of functioning of local power supply systems, as a consequence of increasing the efficiency of choosing the places of optimal placement of flexible generation sources.

Improve decision-making algorithms in multi-agent systems for managing the behavior of active consumers by choosing the optimal mode of interaction based on the formation and solution of a complex optimization problem, which allows to develop problem-oriented algorithms for MAS.

Publications

Rybii Mykhailo. Multi-agent management, development, determination of algorithms for optimal functioning of consumption in local systems with flexible generation and active consumers/Scientific and technical conference (based on the results of dissertation research of undergraduates). [Electronic resource]. URL:https://www.iee.kpi.ua/Scientific and technical conference of IEE undergraduates (based on the results of dissertation research of undergraduates)

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Rybii Mykhailo. Prosumers in the socio-technical field of Smart Grid. [Electronic resource]. URL:https://www.iee.kpi.ua/Scientific and technical conference of KPI masters

Software

To write a master's thesis, such programs were used as: MS Excel, MS PowerPoint, Paint, Word.

Keywords

Multi-agent control, flexible generation systems, active electricity consumers, Multi-agent systems, agent, intelligent system, agent system technique, prosumers, Smart Grid, system optimization.

Annotation

The main idea is to modernize the existing system by applying the method of neural networks based on multiagent control (Smart Grid) and to consider the optimal algorithm for optimizing energy consumption with generation.

An accordance with the theories of the Smart Grid concept, the electric sector of the world's leading countries is being modernized with one of the areas used is the development of multi-agent systems, the emergence of new agents called "prosumers" (active consumers) in local electricity markets, unconditional introduction of flexible generation.

Multi-agent technologies are becoming more widespread in power systems at hierarchical levels, in particular in two aspects: as a methodological apparatus for modeling power systems in solving various problems, and as a platform for building control systems for different purposes. Currently, there is considerable experience in using a multi-agent approach to solving various problems of electricity.

Flexible generation in power systems significantly affects the change in the behavior of agents in the local electricity market. It also influences the formation of tariff policy in the energy market and the maintenance of network modes.

Multi-agent control systems (MACS) of electric power systems, where each agent is an equal participant in the process, provide an opportunity to implement the functions of automatic control of damage detection and localization, selection and rapid recovery of power supply, collection and processing of information. This allows you to make the grid more self-managing and renewable. The cost-effectiveness of their management is achieved due to the possibility of prompt compensation for adverse effects on the parameters of the regime. For example, voltage regulation in addition to the use of traditional means, which can be implemented by changing the generation of active or reactive power, changing the modes of operation of energy storage devices, active load control, and so on.

Artificial intelligence and neural networks also influence the solution of issues related to improving the optimization of the power grid on power systems in general. The method of neural networks is based on the principles of learning large data sets and processing. Accordingly, to train one neuron, a large amount of data must be passed through it. Then he will be able to independently, without human intervention, program and find the optimal solutions needed by the power system.

So, we have a problem of optimal use of energy resources. Wee need to adjust the consumption for each system. Introduce efficient use of generation and its connection with the central system. Businesses need to introduce renewable energy sources into their own consumption, this can help reduce all the negative factors from price to energy overload.

To do this, you need to enter the following main factors:

Development model of interaction between the main equipment of the active consumer, flexible generation, as well as the interaction between the active consumer and the power supply network.

Creating a methodology for assessing the functioning of individual active consumer equipment in local power supply systems and in general in the presence of flexible sources of production.

Improve the way you optimize the mode for certain types to get the most out of your participants and choose the most effective modes.

LIST OF ABBREVIATIONS

(MMPS) Managing modern power systems

(MACS) Multi-agent control systems

(MAS) Multi-agent systems

(KQML) Knowledge Query Manipulation Language

(CAL) Communication Agent Language

(PV) Photovoltaic

(RA) Active agent - Prosumer

(CA) Coordinating Agent

(TS) Time series

(ANNs) Artificial neural networks

(NNs) Neural networks

(SNN) Supply neural networks

(NARX) Neural networks - nonlinear autoregressive with exogenous inputs

(FF) Supply neural networks

(RE) Backpropagation neural networks

(RBF) Radial basis neural networks

(RNN) Random neural networks

(PNN) Periodic neural networks

(SCNN) Self-organizing competing neural networks

(MSE) Mean square error

(NRMSE) Normalized root mean square error

(MAE) Average absolute error

(MAPE) Maximum absolute percentage error

(MACS) Multi-agent control systems

(AC) Active consumer

(PBC) Photovoltaic battery capacity

(WPPs) Wind power plants

(SPPs) Solar power plants

MAINTENANCE

INTRODUCTION

In recent decades, information technology is actively used in energy. They assist in design, operation and forecasting. Given the current amount of information related to the production, transmission and consumption of electricity, not only is it impossible to abandon the use of computers, but the prospects for the use of new and new means of transmission, processing and output of information are constantly being considered.

Simple primitive programs began to be replaced by information-analytical complexes and expert systems, neural networks were actively developed. The beginning of the development of specialized expert systems and neural networks was the appeal of the energy industry to the field of neural network intelligence.

The next step in this direction may be multiagent (or multiagent) systems. From the transition to smart grids expect the flow of information following the flow of energy. This flow needs to be processed, interpreted and adequate action taken. Today, it is possible to solve these problems with the help of software, but research in the field of artificial neural networks has proven the effectiveness and feasibility of training programs (and without human intervention).

The complexity of managing modern power systems (MMPS) is so great that centralized control becomes inefficient, so new approaches to the organization of control of such multisystem are being developed. The development of the Smart Grid concept leads to significant changes in approaches to the organization of control systems, including the rules of interaction of electricity market participants. This creates new participants and additional opportunities. The multi-agent approach as a component of this concept has a number of advantages and allows to solve various problems of management in electric power systems effectively.

For about twenty years, the world has known the use of multi-agent systems (MAS) in the power industry. Multi-agent technologies have been developed for a number of applications, including: diagnostics, condition monitoring, power system recovery, market modeling, network management and automation

In the process of designing agents, the requirements for the operation of each agent are determined within the requirements of a particular multi-agent system. This means that if the requirements for the MAS change, the agents must also be changed, ie in the general case, the agents cannot be removed from the system to operate within another system or offline. Thus, agents cannot have a goal that is useful only to the agent itself, or one goal for several MAS simultaneously.

The stage of determining the requirements can be implicitly "stretched" to the design stage, because this is where the requirements for each specific agent are determined. That is, formally, the design stage does not involve defining the requirements for the system as a whole, but it is at this stage that the requirements for agents are defined, which are considered as a software product that can act independently based on their observations of the environment.

This approach is used, for example, in the method of Tropos, where at the stage of definition, formulate the requirements for the system, at the stage of architectural design define the subsystems that are considered as independent modules. The purpose of this method is consumers, who can actually be interpreted as agents. Then move on to the second phase - the division of subsystems into agents, for which the stages of determining the requirements, design and implementation within the adopted methodology, i.e there is a repetition of the same stages of design as for the system as a whole. In the process of designing MAS, the stages of developing their own systems and developing individual agents are similar. This gives grounds to consider the software agent as a separate system with specific requirements for interaction that are imposed at the system-wide level, and therefore apply the same techniques and design techniques as for the system as a whole.

In the described unification of the process of designing a multi-agent system, the question of communication of agents or subsystems with each other arises. The essence of the problem is that at different levels of division of the system into components, different communication protocols can be effective, which correspond to the levels of abstraction of the subject area for such partitioning.

The creation of a methodology for the development of multi-agent control systems in the power industry allows to develop interoperable systems for any application and give them a number of characteristics and advantages inherent in the MAS as a whole.

The impact of smart grid savings will be influenced by a number of factors that are largely a consequence of the "containment effect". A smart grid is the main mechanism for achieving aggressive national energy saving and emission reduction targets. The concept is defined by an "intelligent network", which has a "smart" behavior and actions of all related entities. Improving the grid has been one of the greatest successes of the modern era, as renewable energy sources are disappearing, leading to electricity shortages and climate change due to greenhouse gas emissions.

Traditional infrastructure focuses on the interaction between generators, transmission system operators and distribution systems. Prosumer integrates information and communication technologies with advanced energy electronic technologies to provide bidirectional flow of electricity and information. The development of multi-agent systems and the emergence of new agents in local electricity markets in general is an urgent scientific and technical task.

1. ANALYSIS OF THE PECULIARITIES OF THE FUNCTIONING OF LOCAL POWER SUPPLY SYSTEMS WITH FLEXIBLE GENERATION AND ACTIVE CONSUMERS (PROSUMERS), THE PECULIARITIES OF THE FUNCTIONING OF THE MAS AT THE LOCAL LEVEL

1.1 Multi-agent system

Multi-agent management is a system that has optimal solutions without external interference. Optimal solution means minimizing energy consumption in a resource-constrained environment.

The main advantage of multi-agent control systems is the flexibility of multi-agent systems. The multi-agent system can be supplemented and modified without rewriting much of the program. Also, these systems have the ability to self-repair and are resistant to failures, thanks to a sufficient supply of components and self-organization.

In the power industry, we propose to consider a multi-agent system, where each participant organizes interaction through certain agents with its own set of goals and priorities. Such agents respond independently to changing environments and interact with other agents to coordinate actions and joint decision-making.

A multi-agent system is a collection of interconnections formed by several interacting intelligent agents. Multi-agent systems can be used to solve problems that are difficult or impossible to solve with a single agent or monolithic system. Examples of such tasks are online commerce, emergency response, and modeling of social structures.

Typically, multi-agent systems are investigated by software agents. Components of a multi-agent system can also be robots, people or teams of people. Multi-agent systems can also contain mixed commands.

In multi-agent systems, self-organization and complex behavior can occur, even if each agent's behavior strategy is fairly simple. The behavior of agents underlies the so-called "aggregate intelligence".

Agents can share their knowledge through a special language and obey the established rules of "communication" (protocols) in the system. Examples of such languages are the Knowledge Query Manipulation Language (KQML) and the Communication Agent Language (CAL).

An agent is software or hardware that resides in an environment and is able to respond autonomously to changes in it.

The agent can change the environment by performing any action. This is a physical action (for example, by closing a normally available network debugging point) or otherwise (for example, storing diagnostic information in a database for other agents to access). According to this definition of autonomy, some existing systems can be classified as agents.

In the power industry, we propose to consider a multi-agent system, where each participant organizes interaction through certain agents with its own set of goals and priorities. Such agents respond independently to changing environments and interact with other agents to coordinate actions and joint decision-making.

Agents in conventional multi-agent systems may or may not be able to interact with each other, but intelligent agents have a social property and therefore must interact with each other.

Any intelligent agent must have the following three characteristics:

• Reactivity allows the agent to respond in a timely manner to changes in his environment and perform certain actions based on these changes.
• Initiative characterizes the agent's result-oriented behavior. This means that the agent will dynamically change his behavior to achieve his own goal.
• Sociality indicates the ability to interact with other intellectual agents.

The development of the Smart Grid concept leads to significant changes in approaches to the organization of control systems, including the rules of interaction of electricity market participants. This creates new participants and additional opportunities.

Among the new members of the Smart Grid are the so-called "prosumers" - these are active substances that both consume and produce energy.

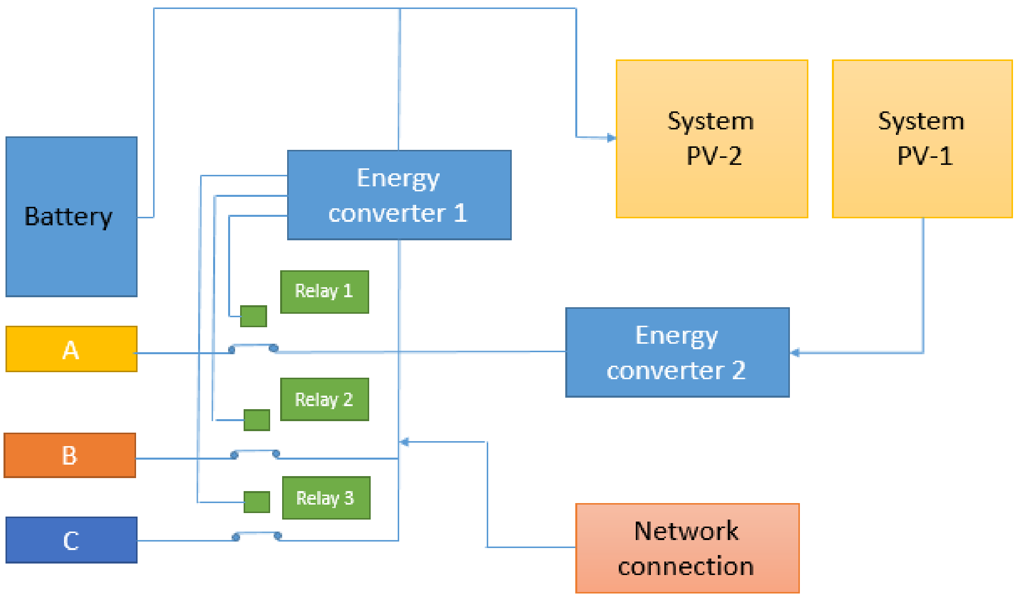


Figure 1. Context of the implementation of the proposed methodology.

The proposed methodology allows you to optimally spend consumer resources to minimize operating costs, reduce electricity bills.

The considered resources are the main network to which the consumer is connected, photovoltaic (PV) systems, energy storage and flexibility of consumption due to load reduction.

The consumer participates in the tariff program used in time, and it is assumed that the introduction of energy into the grid is possible and a reward.

The methodology is modeled for implementation in different consumer conditions and the amount of resources.

Figure 1 shows the context for developing the proposed methodology with regard to the household consumer, but it can be applied to other types of consumers who are also "consumers". The methodology believes that the production of photovoltaic energy can be used freely, on the contrary, the cost of using photovoltaic energy should be added to the target function and the priorities of energy supply should be revised.

It is believed that PV has a property above all others, which means that the generation of PV, if it is available, will always be consumed, or the need for load, battery charge, or accumulated in the network.

Network interaction involves bidirectionality, otherwise there may be cases where this is not allowed due to restrictions, in the physical network or in the legislation currently in use. In these situations. requires a generator, which is used mainly for self-loading without input to the network.

The consumer can use photovoltaic batteries, accumulators and generation to avoid grid consumption during periods when energy is expensive, and take advantage of reduced tariffs to charge the battery or meet consumption.

The methodology is to minimize the energy purchased from the grid to ensure its consumption, as well as take advantage of PV generation and demand for generation to maximize the flexibility provided by the battery system. The methodology considers the optimization process, which works alongside other resources, as a consumer management system to improve energy efficiency and savings.

The coordinating agent is responsible for controlling the methodology. The responsibility of the coordinating agent is basically twofold:

• one - to receive offers from consumer agents and return their domestic prices, managing local energy trade in the energy distribution region;

• other - trade with retailers on behalf of the entire energy distribution region to buy or sell electricity to balance energy shortages or surpluses in the region.

Some coordinators are also concerned about the restriction of physical networks in their energy distribution regions, but this is beyond the scope of this document, which limits the coordinator as a local market operator rather than as a system operator.

Prosumer agents represent autonomous distributors in the distribution of p2p energy. Referring to the abstract architecture for agents, the set of prospecting agents is denoted by:

$$E_A = [PA_1, PA_2, PA_N] \tag{1}$$

Where, N - is the number of consumers involved in the distribution of p2p energy. Each agent perceives his environment to gather the information needed to make decisions.

1.2 Initial agent environment

$$E_{PA} = [p^{internal}, A, D, P^{renewable}] \tag{2}$$

$p^{internal}$ - represents the set of domestic prices in the mechanism of energy distribution P2P.

A - a set of parameters of electrical devices (devices, energy storage systems and distributed generators).

D - consumer demand (for example, the use of hot water during the day).

$P^{renewable}$ - it is a set of produced energy of uncontrolled production of renewable sources, which belongs to the consumer.

Based on information received from the environment, the managing agent plans its electrical devices to minimize electricity costs to maximize its revenues within the p2p energy distribution.

This process is modeled by a decision model that is abstractly described as follows:

Active agent - Prosumer (RA):

$$\begin{aligned} &\min \frac{\cos t}{T}(p^{internal}, p^{renewable}, x) \\ &s.t.\, f(x, A, D) = 0 \\ &h(x, A, D) \le 0 \end{aligned} \tag{3}$$

T - a set of time steps that are taken into account throughout the planning horizon.

X - variable solutions, which represent the operating state of the controlled electrical devices (for example, the state of on / off machines, the heating power of the electric water heater, etc.).

Cost - is a function of the internal price of electricity, renewable products and the working condition of electrical appliances, the value of which is the total cost of electricity throughout the planning horizon.

f i s - is a constraint on equality and inequality that takes into account the physical boundaries of the device and consumer satisfaction.

The set of actions of a semi-professional active agent:

$$AC_{PA} = [x, e^{bid}, [p^{bid}]] \tag{4}$$

e^{bid} and p^{bid} - represent energy supply and price respectively.

Full action

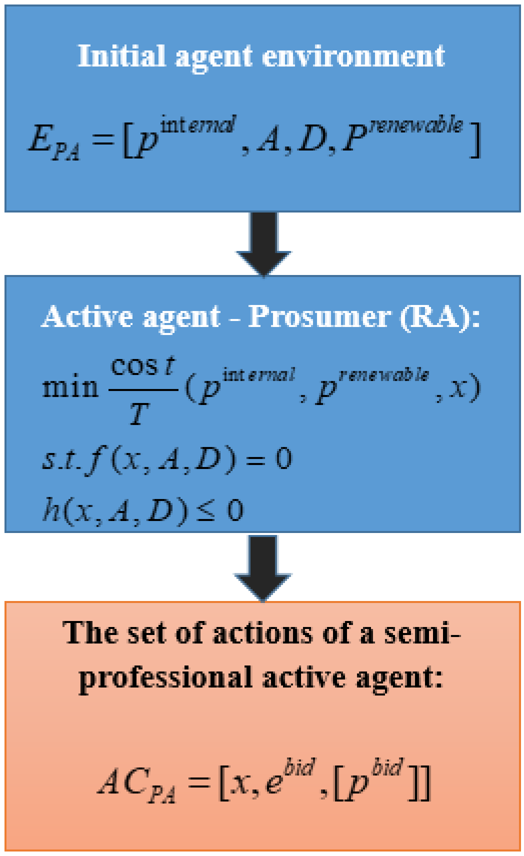


Figure 2. Abstract architecture of semi-professional agents.

1.3 Coordinating agent environment

Based on the information perceived from the set of actions of the professional active agent, the coordinating agent plans its environment to minimize losses and maximize work.

Initial coordinator agent environment:

$$E_{CA} = \{p^{external}, e^{\text{bid}} P^{\text{bid}}\} \tag{5}$$

$e^{exchange}$ - denotes the energy traded by retailers.

e^{bid} and p^{bid} - represent energy supply and price respectively.

Coordinating Agent (CA):

Pricing model

$$p^{\text{internal}} = \text{Pricing}(p^{\text{external}}, e^{\text{bid}}, p^{\text{bid}}) \tag{6}$$

$p^{internal}$ - represents the set of domestic prices in the mechanism of P2P energy distribution.

$p^{external}$ - represents the set of external prices in the P2P energy distribution mechanism.

Actions of the coordinating agent:

$$AC_{CA} = \{p^{internal}, e^{exchange}\} \tag{7}$$

$e^{exchange}$ - represents changes in energy.

Full action

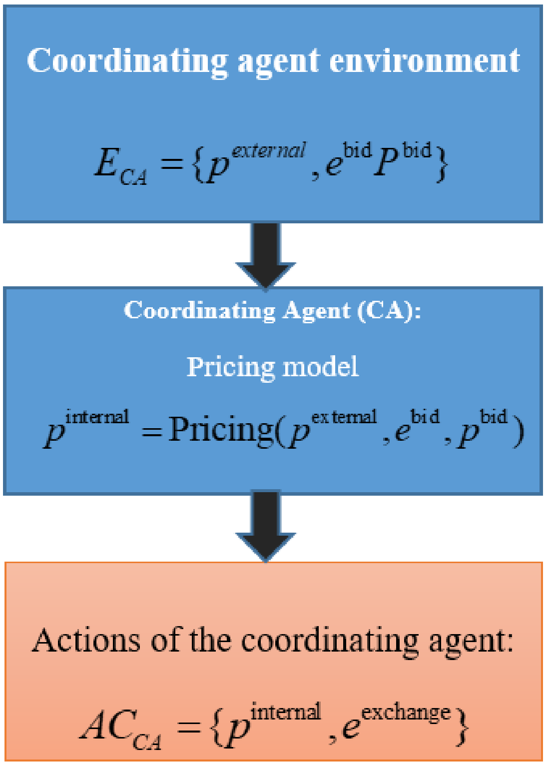


Figure 3. Abstract architecture of the coordinating agent.

1.4 Mathematical architectural component of periodic functions of the intelligent network

Based on the proposed method above, the system can further use the method of individual components to calculate circuits with electrical energy converters with complex functional relationships between generator and load. This means that in the future the system is able to characterize different types of complex periodic functions. The basic mathematical functions of Laplace modeling are taken as a basis.

Basic principles of image formation of complex periodic functions. Consider different types of complex periodic functions formed from elementary mathematical functions, which we call basic. We write them and their images in a table. 1, and we will use such notation of types of functions at the further consideration both for designation of the basic functions, and for designation of difficult periodic functions which are based on the corresponding basic (as it will be visible from further consideration, only from basic functions the function of type 1 is applied at construction of images of all types of complex periodic functions, other basic functions are used to construct images only of the corresponding type of complex periodic functions).

Image $F_P(p)$ the function of the signal u(t) for the case of rectangular pulses with amplitude Ui has the form:

$$F_P(p) = \frac{1}{p}\frac{(1-e^{-pT})}{(1-e^{-pT_n})}\sum_{i=1}^{n} U_i e^{-(i-1)pT} \qquad (8)$$

Table 1. Functions of signals.

Type	title	Basic function $f_{Б,i}(t)$	Image $F_{Б,i}(t)$
1	Level function	$F_{P,1}(t) = A$	$F_{P,1}(t) = \frac{A}{p}$
2	Sinusoidal function	$F_{P,2}(t) = \sin\omega t$	$F_{P,2}(t) = \frac{\omega}{p^2+\omega^2}$
3	Exponential function	$F_{P,3}(t) = e^{-\alpha t}$	$F_{P,3}(t) = \frac{1}{p+\alpha}$
4	Function of direct proportionality	$F_{P,4}(t) = At$	$F_{P,4}(t) = \frac{A}{p^2}$

When the approximation intervals of the function have different durations $T_i = \text{var},$ which is a more general case, the image of the signal function is as follows:

$$F_P(p) = \frac{1}{p}\frac{1}{(1-e^{-pT_n})}\sum_{i=1}^{n} U_i (e^{-pT_{(i-1)}} - e^{-pT_i}) \qquad (9)$$

The calculations according to (2) are more complicated in comparison with (1), but in some cases the implementation of the approximation of the generator signal function can simplify the calculations by reducing the number of approximation intervals by combining intervals with the same amplitudes of step pulses.

When constructing modulated functions and signal functions, to approximate which it is necessary to apply several basic functions, it is necessary to use the alternation of the main function with a pause to form a complex basic function.

$$T_i + T_o = T_p \tag{10}$$

Where T_i – duration of the basic function.

T_o – pause duration.

$$F_i(0+t) = F_i(T_i + T_o + t) \tag{11}$$

Then the image of the signal function has the form:

$$F_P(p) = \frac{1}{p}\frac{(1-e^{-pT})}{(1-e^{-pT_n})}\sum_{i=1}^{n} U_i e^{-2(i-1)pT} \tag{12}$$

The shift of the whole function is carried out by the delay theorem by multiplying by e^{-pT}.

We build images of complex periodic functions created on the basis of basic functions according to table 1.

Construction of images and original currents for complex generator functions based on the level function

Consider the functions based on the level function, sinusoidal function, exponential function and function of direct proportionality.

Consider the first stage of solving the problem of finding i(t) by means of the Laplace transform - the search for images of functions e(p). To do this, we use the delay theorem, according to which:

$$f(t-t_0) \doteq e^{-pt_0}F(p) \tag{13}$$

The periodization of individual components is as follows: according to the delay theorem, the image of the periodized function $F_p(p)$ will look like:

$$F(p) = F_p(p)(1 + e^{-pT} + e^{-p2T} + \ldots) = \frac{F_1(p)}{1-e^{-pT}} \tag{14}$$

Where, T – function repetition period $F_1(p)$.

Every period T_P is formed by the sum of three pulses:

$$F_P(p) = F_1(p) + F_2(p) + F_3(p) = \sum_{i=1}^{3} F_i(p) \tag{15}$$

The specified function will look like:

$$F(p)=\frac{F_1(p)+F_2(p)+F_3(p)}{1-e^{-pT_n}} \tag{16}$$

Let's write it down $F_1(p), F_2(p), F_3(p)$ taking into account formula in table 2.

Summarize the formulas in the table for *i* nested periods:

$$F_T(p)=\frac{1}{p}(1-e^{-pT})\sum_{i=1}^{3} U_i e^{-(i-1)pT} \tag{17}$$

For the established periodic mode of operation of the system (4.9) will be written:

$$F(p)=\frac{1}{p}\frac{(1-e^{-pT})}{(1-e^{-pT_n})}\sum_{i=1}^{3} U_i e^{-(i-1)pT} \tag{18}$$

Construction of load resistance images is carried out by determining the active resistance in the image area R, inductive resistance in the image area pL and capacitive resistance in the image area $\frac{1}{pC}$. According to the case considered in the work, we have a case RL - the load represented in the image area $Z(p)=R+pL$.

In a more generalized case, the paper considers the case of different values of active resistance at different intervals of the circuit. To take this into account at each interval of the load image has different values:

$$Z_i(p)=R_i+pL \tag{19}$$

Where, i – interval number.

The image of currents at intervals is in accordance with Ohm's law, which also applies to the field of images:

$$I_i(p)=\frac{U_i}{Z_i} \tag{20}$$

Features of the implementation of the algorithm for finding the original currents will be shown by example. Find the original currents using the inverse Laplace transform. Consider the case when the period of the system consists of two intervals ($n=2$), $U_1=U$, $U_2=2U$, $R_1=R$, $R_2=R$, $Z(p)=R+pL$.

The current image will then be recorded:

$$I_1(p)=\frac{U(p)}{Z(p)}=\frac{U(1-e^{-pT})(1+2e^{-pT})}{p(1-e^{-2pT})(R+pL)} \tag{21}$$

The original current in the interval is as the transient difference $i_{P,i}(t)$ (which is the result of the operation of the generator on the interval that is calculated) and free (which is the result of the operation of generators on all other intervals, except that which is calculated) $i_{V,i}(t)$ currents:

$$i_i(t) = i_{P,i}(t) - i_{V,i}(t). \quad (22)$$

Determine the transient current $i_{P,1}(t)$. When determining the transient current, the components of the generator functions that operate only on the calculated interval are considered. When calculating the surplus, all the roots of the denominator are used, both the roots determined by the load and the roots determined by the generator.

The steady load current on the first interval has the form:

$$i_1(t) = \frac{U}{R}\left[1 - e^{-\frac{R}{L}t} + \frac{2 - 2e^{-\frac{R}{L}T} + e^{-\frac{R}{L}T} - e^{-2\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} e^{-\frac{R}{L}t}\right]. \quad (23)$$

Decompose the expression into terms:

$$i_1(t) = \frac{U}{R}\left[1 - e^{-\frac{R}{L}t} + \left(\frac{2}{(1 - e^{-2\frac{R}{L}T})} - \frac{2e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} + \frac{e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} - \frac{e^{-\frac{R}{L}T} e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})}\right) e^{-\frac{R}{L}t}\right]. \quad (24)$$

Let's analyze the expression for each term; for this we present in the form:

Where, $i_1(t) = \frac{U}{R}\left[A_1 + A_2 + A_3 + A_4 + A_5 + A_6\right]$,

$$A_1 = 1;\ A_2 = -e^{-\frac{R}{L}t};\quad A_3 = \frac{2}{(1 - e^{-2\frac{R}{L}T})} e^{-\frac{R}{L}t};$$

$$A_4 = -\frac{2e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} e^{-\frac{R}{L}t};\quad A_5 = \frac{e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} e^{-\frac{R}{L}t};\quad A_6 = -\frac{e^{-\frac{R}{L}T} e^{-\frac{R}{L}T}}{(1 - e^{-2\frac{R}{L}T})} e^{-\frac{R}{L}t} \quad (25)$$

Note that the first two terms A_1, A_2 form a transient current and are determined by the parameters of only the current first interval.

Terms A_3, A_4, A_5 and A_6 which form a free current are determined by the parameters of the circuit elements at all intervals. Positive terms determine the free currents generated when the voltage pulse is turned off, negative - when turned on. The rate of descent depends on the parameters of the load at intervals (here is the case for a constant value of the load, the case for non-stationary load will be discussed below).

Terms A_3 shows the decrease only on the current first interval, the term A_4, A_5 in addition, - on the previous to the value of time $t=T$ (on the other), and terms A_6 , except for the current first, - on the previous second interval of the previous period to the time value $t=T$ and in the first interval of the previous period - to the value of time $t=T$. Accordingly, the attenuation functions are determined by the parameters of the elements at appropriate intervals (first consider the first period), for which we can write:

$$i(t)=\frac{U}{R}\left[1-e^{-\sigma_1 t}+\left(2-2e^{-\sigma_2 T}+e^{-\sigma_2 T}-e^{-\sigma_2 T}e^{-\sigma_1 T}\right)e^{-\sigma_1 t}\right] \tag{26}$$

Where, $\sigma_i = R_i/L$.

Let's move on to the case when the load changes with each interval

$$R_i=\left\{R_i \middle| t\in\left[t_{i-1},t_i\right),\cup t\in\left[t_{i-1},t_i\right)=T_{II}, R(t)=R(t+T_{II})\right\} \tag{27}$$

Based on the formula, in the first interval, the free current will be recorded as follows:

$$i_{V,1}(t)=-(I_3(1-e^{-\sigma_3 T})+I_2(1-e^{-\sigma_2 T})e^{-\sigma_3 T}+I_1(1-e^{-\sigma_1 T})e^{-\sigma_2 T}e^{-\sigma_3 T})e^{-\sigma_1 t} \tag{28}$$

It takes into account an infinite number of previous periods of system operation and magnitude $I_i(1-e^{-\sigma\,T})$ takes into account the decrease of currents of the previous interval (the current interval is considered the first interval of the current period).

The calculation of transient currents is carried out according to the above method:

$$i_{P,i}(t)=Ree\frac{U_i}{p(R_i+pL)}e^{pT}\Big|_{p_1=0}+Ree\frac{U_i}{p(R_i+pL)}e^{pT}\Big|_{p_2=-\sigma_i}=\frac{U_i}{R_i}(1-e^{-\sigma_i t}) \tag{29}$$

In this section the mathematical methods of determination of potential of the active consumer (AS) on the basis of algorithms of a choice of a mode of functioning were considered. The intelligent network is described in relation to complex power system devices that interact with each other at the local level using mathematical basic models of Laplace functions. For Microgrid to work effectively, the problems that need to be solved and their solutions that optimize energy processes in local power grids are presented. Among the issues that needed to be addressed were: optimal reconfiguration of electrical networks, generation and compensation of reactive power and power balancing in the network.

Based on the analysis of prospects for the development of modern power systems, the main directions of modernization of local power systems with the use of active consumers (prosumers) and virtual power plants are identified.

It is shown that the effective functioning of local systems, which include FDG(flexible dispersed generation) based on different types of RES(renewable energy sources) and different types of prosumers.

It is impossible without building systems based on multi-agent control using aggregators of energy generators and load aggregators for consumers (coordinating agents).

The operating environment of active agents and coordinating agent is presented in detail with the formation of appropriate optimization procedures, in particular, minimization of energy consumption in conditions of resource constraints.

Conclusion for 1 question

A multi-agent system is a system that has a set of relationships that are formed by several interacting intelligent agents with each other. The multi-agent system must respond in a timely manner to system failures, quickly and thoroughly eliminate deficiencies without external intervention.

Each agent has its own environment, where it can be both a governing system and a system that is managed.

The multi-agent system should optimize the power grid and simplify the typical losses for the consumer. The system should increase economic efficiency through the introduction of Smart Grid and its components. The multi-agent system is based on such applications as NetLogo, VisualBots, MASON, REPAST, JADE, SemanticAgent, CogniTAO - C ++.

The multi-agent system has active agents that act as consumers. They are able to create their own system by combining. The method of photovoltaics, which has high efficiency due to active agents, is presented

2. CONSTRUCTION OF THE MAS MODEL ON NEURAL NETWORKS AND OPERATION IN LOCAL SMART GRID SYSTEMS

Energy efficiency is a property of technology, production or systems that characterizes the use of energy per unit of final product. Improving energy efficiency is possible through the gradual implementation of systems that focus on organizational and technical measures. Problems of energy efficiency increase are related to forecasting energy consumption, which should be timely and reliable.

Forecasting results are the basis for the formation of effective forecasting management solutions. The development of forecasting tools, first of all, involves the collection of information, analysis of information, identification of patterns and trends and prospects in the electricity market.

The results of energy efficiency forecasting can be used to predict situations and problems that may lead to negative consequences. Based on forecasts, the development of the energy sector is carried out. Today, the field of energy efficiency needs human control, but there are many factors that affect performance. These factors do not allow to process the received data effectively and precisely.

Most often, the comparison of the forecast is made by the value of the root mean square error or the mean approximation error. If the results of the comparison meet the requirements of a given accuracy criterion, then forecasting tools can be used to make predictions.

This can be done by expert forecasting systems, but only in part. It is advisable to use a mechanism that will have great stability, which can find hidden patterns in the data. There are also categories of problems that cannot be formulated as an algorithm. These are problems that depend on many subtle factors that the brain can calculate, but not exactly.

Energy consumption planning and forecasting are related and have common features. Planning determines the necessary measures to achieve the set objectives, and forecasting provides identification of patterns and trends in energy consumption. If there are negative trends as a result of the forecast, the plan identifies measures to neutralize the negative problems and consequences.

The topic of scientific and practical research is forecasting the demand for electricity. The goal formulates the result of the forecasting study, as well as indicates the object and subject of the study and is implemented through a number of specific tasks. The subject of scientific and practical research is forecasting models and methods of forecasting electricity demand. The object of scientific and practical research is the process of forecasting electricity needs.

2.1 Development of a neural network for forecasting electricity consumption

Electrical load forecasting provides the basic source information for decision-making in the management of power systems in the process of planning their normal electrical conditions.

Based on load forecasting, input, output and optimal modes of electrical systems are calculated, stability, reliability, percentage of efficiency are estimated. Most methods of forecasting electrical load, developed in the power industry, are mixed methods of different statistical processing operations. There are also forecasting methods in which the separation of the basic component in the graphs of load changes. The prediction tool for decision-making in the power industry is the prediction of electrical load. So far, many combined and simple methods and models for predicting the electrical load of energy systems have been developed.

Some methods lead to significant quadratic errors of the predicted values, others - due to the complexity of the mathematical apparatus have not been widely used to solve practical problems of electric power.

To date, the issue of developing methods for forecasting the load is very relevant. One of the best prediction methods is the time series prediction method based on artificial neural networks. Neural networks originated from the sequential learning of numerical values.

Time series (TS) - is a sequence of values that describe the process in time, measured at successive points in time, usually at regular intervals. The time series is characterized by auto regression methods, which express a number of values that affect the processing data.

The auto regression method expresses the dependence of the quantity on the factors influencing by means of a linear model. Auto regression models of order p are defined as follows:

$$X_t = c + \sum_{i=1}^{p} a_i X_{t-i} + \sum t \qquad (30)$$

where, c - is a constant value that describes the state of passage of factors influencing the origin. It characterizes the model and shows when the factors are zero; a_i - coefficients that characterize the degree of dependence of the total parameter X_t from the influencing factors, from what was the parameter at the last regression step; $\sum t$ - model error - is the difference between the calculated value of the model during the period and the known data.

The autoregression method makes it possible to show the dependence of the parameter on itself in the previous period of time (day, month, year). It is the search for this characteristic that allows us to build accurate models that can be used to make predictions.

The process of autoregression of the “p” order in its classical nature can be represented in the form:

$$y_t = p_1 y_{t-1} + p_2 y_{t-2} + ... + p_p y_{t-p} + e_t \tag{31}$$

The process of variable average “q” order in its classical nature can be represented in the form:

$$y_t = e_t + \theta_1 e_{t-1} + \theta_2 e_{t-2} + ... + \theta_q e_{t-q} \tag{32}$$

<u>Advantages of the Method</u>

• Obtaining high-quality characteristics of the model with adequate forecast with a minimum of time and input requirements.

<u>Disadvantages of the Method</u>

• The forecast according to the input data is only single. If you want to make a forecast for a longer period of time, then as influencing factors for the calculation will have to take not the actual parameter Xt, but one that is calculated by the model, which will eventually give a forecast on the forecast. This forecast is not adequate.

• As autoregression increases, it is necessary to expand the range of input data to model predictions.

This method allows to obtain normal forecast results in stable situations where there are no abrupt climate changes. However, in the event of an unexpected sharp change in external parameters, the application of such an approach does not allow to correctly predict the situation. However, the situation can be improved by the "decision tree method".

<u>The decision tree method</u> - is one of the most popular methods for solving electrical problems, classification and forecasting. If the dependent variable acquires discrete constant values, then the classification tree solves the classification problem. If the dependent variable takes continuous values, then the decision tree establishes the dependence of this variable on independent variables.

The decision tree was first proposed by Howland and Hunt in the late 1950s. In its simplest form, the "decision tree" is a way of presenting rules in a hierarchical, consistent structure of schemes. The basis of this structure is the answer "Yes" or "No" to a number of questions. This method characterizes the actions of "exclusion".

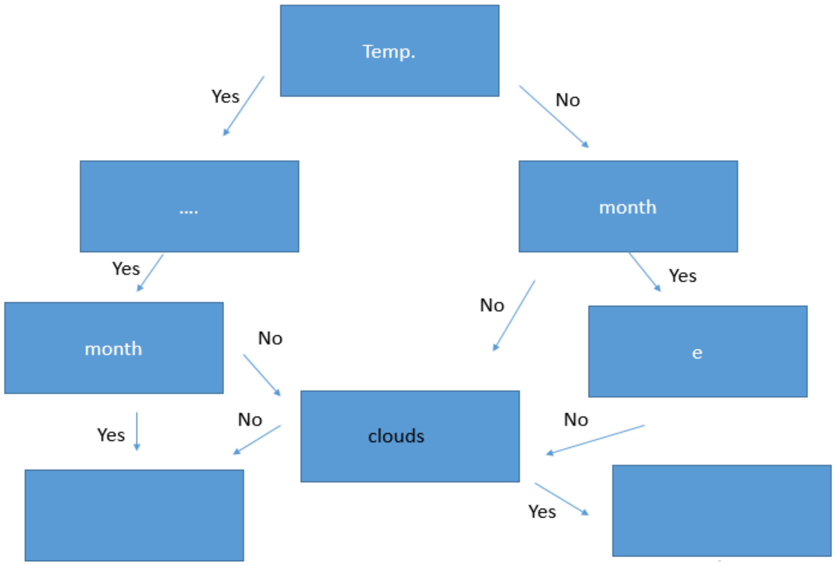


Figure 4. The basic structure “decision tree”.

The "tree" method is not optimal in our time because the energy infrastructure is constantly evolving.

Recently, artificial neural networks (ANNs) have been attracting more and more attention from time series forecasting specialists, and in particular from electricity consumption series. Neural networks are also used for prediction - systems that have the advantage of self-learning and imitation of the human brain.

The state of the neuron is determined by the formula:

$$S = \sum_{i=1}^{n} x_i w_j \tag{33}$$

Where, n - is the number of neuron inputs, x_j - the value of the i-th input of the neuron; w_j - the weight of the i-th synapse.

The accuracy of forecasting is assessed by factors. Each forecast is estimated not earlier than after a period of time equal to the calculation interval that has elapsed since the execution of the forecast. In the general case, it is recommended to use the following indicators to assess accuracy:

Average module of forecasting errors:

$$E = \frac{1}{n}\sum_{i=1}^{n} | Y_{f1} - Y_{f2} | \tag{34}$$

Where, Y_{f1} - the actual value of the parameter; Y_{f2} - forecast value of the parameter; n - the number of points on the calculation interval.

Artificial neural networks are complex analytical systems in which the tasks must be clearly controlled. Insufficient accuracy of problem formulation is replaced by the ability to self-study, the ability to find in the data hidden and obscure images, dependent time errors and fuzzy data.

The advantage of using artificial neural networks to forecast electricity consumption is the ability to use a large number of different input parameters: input data of electricity consumption and the corresponding initial weather conditions, weather forecasts, time characteristics of the day, seasons, types of days. The function of the influence of input parameters on the output result can be of different complexity.

The main property of artificial neural networks is the ability to adapt their behavior and use knowledge depending on changes in the environment. Analysis of existing methods described that the most promising is the use of neural networks. Electricity consumption depends on many parameters. These can be working days or weekends, seasonal, seasons, temperature characteristics, clouds, humidity and others.

The system is based on neural networks, has a stable mechanism for processing large data streams. The system will gain experience and results based on the hidden mathematical laws of processing data.

Neural network - is a nonlinear system that allows much better classification and characterization of data, efficiently and accurately process them than any linear method. The most important advantage of such a system is: No need for programming.

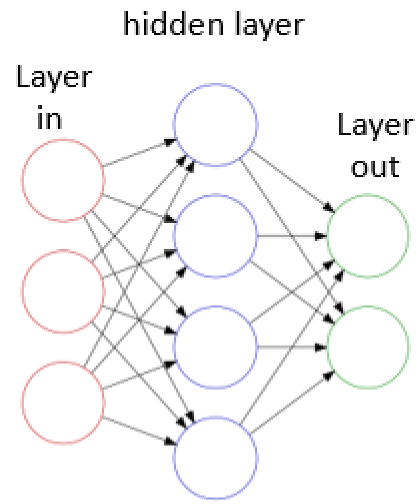


Figure 5. Network neurons.

Each circular node is an artificial neuron, and the arrows are the connection between the output of one artificial neuron and the input of another.

The neural network, depending on the time of data processing, is able to be upgraded on the basis of a huge training sample of data, which distinguishes it from the expert system.

The use of artificial neural networks is similar to the successful use of functioning biological systems that operate on a large scale, they have the opportunity to evolve.

Development procedures reveal the ability of neural networks to summarize, process, and associate data. After successful modernization, neural networks can find adequate and accurate solutions to tasks and problems of the same class that were not identified in the learning process. This leads to a high degree of stability and flexibility of the system when changing the input data.

Neural network prediction can be used to search for anomalous values and high-class problems, or values that are extracted from statistics.

Since the size of the database of consumption graphs must be clear enough for the forecast to be reliable and accurate, it is appropriate to use modern mathematical approaches to process graphs. These are mathematical models that are used in artificial neural networks (ANNs).

The development and research of forecasting methods based on neural networks has a significant amount of modern research. The use of neural networks (NNs) allows to increase the efficiency of the power management system, to identify technical problems for the rather complex structure of industrial and domestic electrical facilities. (MicroGrid and SmartGrid).

Thus, the development of a method for predicting a discrete numerical series of electricity consumption based on the use of artificial neural networks is relevant and relevant today. It is able to characterize accurate forecasts.

The following typical neural network tasks can be identified:

- Automation of processes and their classification;
- Forecasting of automation processes;
- The process of modernization;
- Decision-making process;
- Management and control;
- Encoding and decoding of streaming information;
- Approximation of dependent data.

Problems of forecasting are associated with insufficient quality and quantity of initial data, changes in the environment in which the process takes place, the influence of subjective factors. The forecast is always made with some error, which depends on the forecast model used and the accuracy of the original data. The task of forecasting neural networks is to obtain an estimate of future initial data and values, which are arranged in time characteristics based on analysis, as well as the impact of trends in factors.

To predict power consumption, it is better to use the configuration of artificial neural networks (ANNs) of direct propagation (perceptrons) with the training method of error backpropagation.

When choosing the structure of an artificial neural network, it is important to consider its size, the number of hidden layers and the number of neurons.

If the size is insufficient, the ANNs will learn poorly and work incorrectly to solve the task, and if the size exceeds the complexity, the ANNs learning process will be very long and time consuming, or the network may not be suitable at all.

This issue is solved in various cases through experimental research. It can be concluded that the method of artificial neural networks is very well suited for predicting time mathematical series, within the problem of predicting electricity consumption. It handles a lot of input well.

2.2 Algorithm for Neural Network Training

As a first step in learning, the neural network must initialize and accept the weights at random, after which the network randomly receives the training sample data. To train several different neural networks, with the same input data, we get an output with an error that we can convert into mathematical data.

In the system, part of the input parameters of the model are numerical data (electricity consumption, air temperature, pressure, time of day), and part - categorical (time of year, types of days, type of clouds). Incomplete use of input parameters is also possible.

For example, through the construction of the ANNs system, each element of which is responsible for its case, the common input of the ANNs system (in) is used to direct data to the input of a particular neuron, the purpose of which is the corresponding predicted situation.

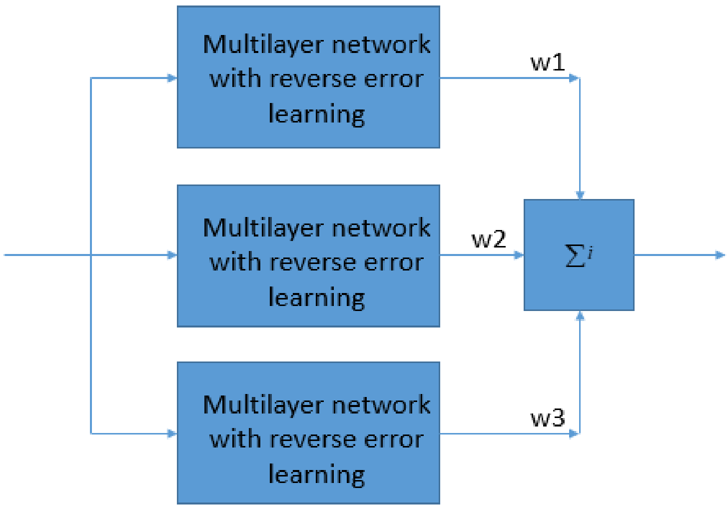


Figure 6. The structure of the developed neural network with the configuration of direct propagation with learning by the method of inverse error propagation.

To increase the accuracy of the prediction, a model created with several artificial neural networks is used. Each artificial neural network performs prediction according to the influence of its factor. Each artificial neural network acts as a perceptron in the classical model. This allows you to increase the accuracy of forecasting.

According to the given algorithm there is a processing for each node. For each indicator that can affect the forecast (temperature, precipitation, weekends), the training of a separate artificial neural network begins.

When the training of each artificial neural network ends, the training of the main artificial neural network begins, which establishes the equilibrium for each artificial neural network, the main neural network determines the impact and quality of which indicator has the greatest impact on electricity consumption.

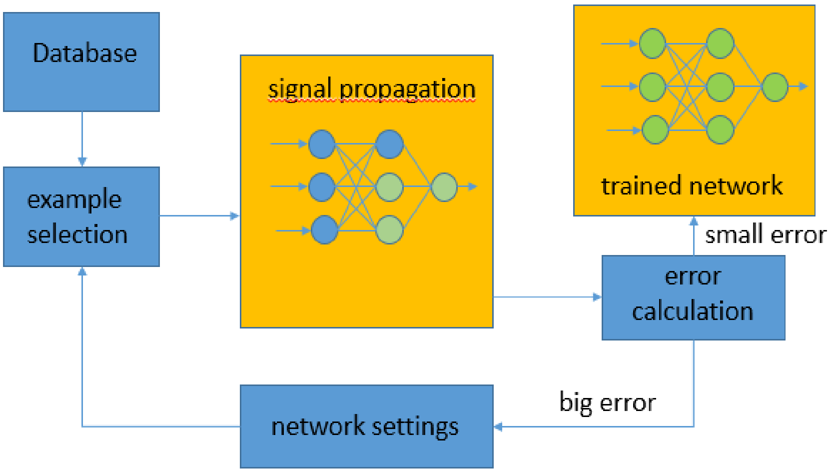


Figure 7. Standard scheme of the learning process of a multilayer perceptron.

For the learning process it is necessary to have a model of the external environment in which the neural network operates - the information needed to solve the problem. Secondly, it is necessary to determine how to modify the weight parameters of the network. A learning algorithm means a process that uses learning rules to set up a network.

There are three general learning paradigms:

- "with a teacher"
- "without a teacher" (self-study)
- mixed

In the first case, the neural network has the correct values for each input example. The data is configured so that the network produces answers as accurate as possible to the known correct answers.

Learning "without a teacher" does not require knowledge of the correct answers to each example of a training sample. In this case, the internal structure of the data and the relationship between the samples in the training set are taken care of, which allows to divide the samples into categories.

In blended learning, part of the data is determined through teacher training, while other data is determined through self-study.

There are many rules of instruction in general use, but most of these rules are some modification of the well-known and oldest rule of instruction, the Heb's rule. This rule applies to the mixed type.

Heb's rule

"If a neuron receives an input signal from another neuron and both are highly active, the weight between the neurons must be amplified." (C) Heb's

When simultaneously exciting two neurons with outputs (xj, yi) at the t-th step of learning, the weight of the synaptic connection between them increases, otherwise – decreases:

$$Wij(k) = rxj(k)yi(k) \tag{35}$$

Where, r - the coefficient of learning speed.

Can be used when teaching "with a teacher" and "without a teacher".

Hopfield's rule

It is similar to Heb's rule except that it determines the amount of gain or weakening. "If both the output and input signals of a neuron are active or inactive, we can increase the data by combining learning scores, otherwise we can decrease the data by learning scores."

The "delta" rule.

This rule is a continuation of the interpretation of the Heb's rule and is one of the most commonly used. This rule is based on the simple idea of continuously changing synaptic data to reduce the mathematical difference ("delta") between the value of the desired and the actual output signal of the neuron.

$$Wij = xj(di - yi). \tag{36}$$

This rule minimizes the root mean square error in the power grid. This rule is also referred to as the Vidrov-Hoff training rule and the least average mathematical squares training rule.

In the "delta" rule, the error is obtained and converted by the derivative of the transfer function and sequentially the transformation is applied in layers to the previous characteristics for the correction of synaptic data. The process of reverse propagation of network errors continues until the first accurate data is reached.

When using the "delta" rule, it is important that the set of input data is disordered. With a well-ordered or structured representation of the learning set, the result of the network may not match the desired accuracy and the network will be considered incapable of learning.

Training by competition

In contrast to Heb's training, in which a plurality of output neurons can be excited simultaneously, in learning by competition, the output neurons compete with each other for activation in the network.

Learning with this competition allows you to combine input and value: such examples are grouped by the network according to correlations and are represented by one element in the data.

The synaptic data of the winning neuron are modified during training. The effect of this rule is achieved due to such a change in the sample stored in the network (vector of synaptic data of the winning neuron), in which it becomes similar to the input example.

The neuron with the largest output signal is the winner and has the ability to slow down its competitors and excite neighbors. The output signal of the winning neuron is used and only it and its neighbors are allowed to adjust their connection data.

$$Wij(k+1) = Wij(k) + r[xj - Wij(k)] \tag{37}$$

Since the winning element is determined by the highest correspondence to the input sample, the Kohonen network simulates the distribution of input values. Training in the Kohonen network is presented below.

2.3 Neural network training based on the Kohonen model

It is advisable to use a neural network with self-organization based on competition, namely the Kohonen network.

In the first step, the weights (v, w) are initialized randomly.

Each input neuron $\{X_i\}_{i=1}^{n}$ sends the received initial signal to all neurons in the next (hidden) layer.

Every hidden neuron $\{Z_j\}_{j=1}^{p}$ summarizes the weighted input signals:

$$Z_j^{in} = \sum_{i=1}^{n} x_i v_{ij} \tag{38}$$

then applies the activation function:

$$Z_j = f(Z_j^{in}) \tag{39}$$

The result is received by all elements of the next (source) layer. Each output neuron $\{y_k\}_{k=1}^{m}$ summarizes the weighted input signals:

$$y_k^{in} = \sum_{j=1}^{p} z_j w_{jk} \tag{40}$$

and applies the activation function by calculating the output signal:

$$y_k = f(y_k^{in}) \tag{41}$$

Next, the error is determined. Every hidden neuron $\{Z_j\}_{j=1}^{p}$ summarizes the error coming from the neurons of the previous layer:

$$\sigma_j^{in} = \sum_{k=1}^{n} \sigma_k w_{jk} \tag{42}$$

Where, σ_k - component of weight adjustment), then calculates the error value by multiplying the obtained value by the derivative of the activation function:

$$\sigma_j = \sigma_f^{in}(z_j^{in}) \tag{43}$$

The next step is to adjust the obtained weights, which are then used as new input to artificial neural networks.

When using neural networks for time forecasting, there is a need for modification, namely, for each of its hours you need to use your own neural network. With the impossibility of accurately adjusting the initial data using the neural network, the question of effective hourly forecasting was adopted.

The principle of operation of this neural network is as follows. In the artificial neural network from the very beginning there is input initial data, but there are no neurons that start all processes. According to the results of the input data, neurons with some random weights are created.

When the following input data is fed into an artificial neural network, the Euclidean distance is calculated - this is the difference between the input vector and the weights. If this distance is large, then a new neuron is created that helps. Thus, the distribution of processing is performed.

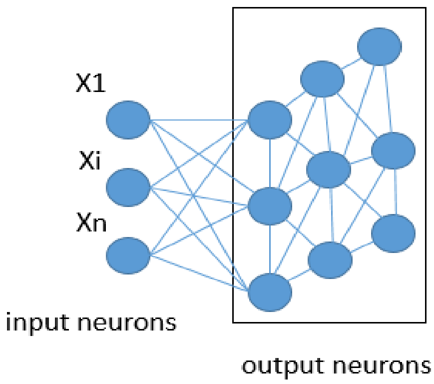


Figure 8. Standard scheme of the Kohonen neural network.

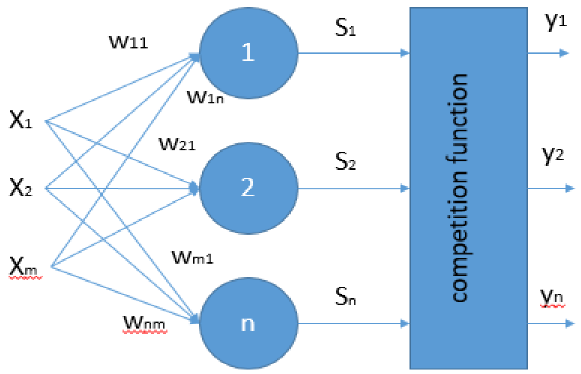


Figure 9. Kohonen neural network learning algorithm.

To solve the problem, each input signal is fed to each of its neurons, after which the winning neuron is determined, which means that this neuron is responsible for a certain day of energy consumption and only for it is the redistribution of the weighting factor.

In the first step of redistribution, the task of the neural network structure is characterized (the number of neurons must correspond to the Kohonen layer).

Then there is a random initialization of weights:

$$|w_{ij}| \leq \frac{1}{\sqrt{M}} \tag{44}$$

Where, M is the number of input network variables. The next step is to submit to the network inputs a random learning example and calculate the Euclidean distances from the input vector to the centers of all:

$$R_j = \sqrt{\sum_{i=1}^{M} (x_i - w_{ij})^2} \tag{45}$$

At the lowest of the values R_j the winning neuron j is selected, which is most close in values to the input vector. For the selected neuron (and only for him) is the correction:

$$w_{ij}^{(q+1)} = w_{ij}^{(q)} + v(x_i - w_{ij}^{(q)}) \tag{46}$$

Where, v - the coefficient of learning speed.

This neural network performs only the classification of input data, is unsuitable for forecasting. As a result, it was decided to combine the Kohonen network and the multilayer perceptron for the preliminary classification of data, which will be used to forecast electricity consumption.

2.4 Model selection (and analysis software)

The number of neurons in the input layer is determined by the number of input parameters (factors), in the output layer - the number of output parameters (considered indicators), in the hidden layer - experimentally based on the results of cross-validation.

Modeling stages:

- Determining the optimal set of factors, to describe as accurately as possible the historical dynamics of the indicators.
- Optimization of the model (network) configuration for each indicator, respectively.
- Hourly forecast of parameters for the day, week and month ahead and assessment of forecast accuracy.

For modeling on the basis of artificial neural networks, the question arises of the need to teach it - to adjust the data of the network branches so that when the signal is applied to the network input to obtain the target value of the output signal.

In the future, the network has the character of learning. The system will use experience to predict the specified parameters and indicators.

Commonly used algorithms for artificial neural networks to predict the electrical load are divided into the following:

- supply neural networks (FF),
- NARX neural networks (nonlinear autoregressive with exogenous inputs),
- backpropagation neural networks (RE),
- radial basis neural networks (RBF),
- random neural networks,
- periodic neural networks and self-organizing competing neural networks.

Weather factors, including temperature, humidity, pressure, wind speed and precipitation, have a significant impact on the energy consumption pattern. However, temperature significantly affects the response to demand. The ratio of temperature and humidity to load is investigated using a correlation coefficient, which is an indicator that describes two sets of data related to each other. This can be a positive or negative factor.

For these two data sets (x and y), the correlation coefficient between x and y (y, xcorcoef) can be calculated as:

$$corcoef_{x,y} = \frac{\sum_{i=1}^{n}(x_i - avg(x)) \times (y_i - avg(y))}{\sqrt{\sum_{i=1}^{n}(x_i - avg_x)^2 \times \sum_{i=1}^{n}(y_i - avg_y)^2}} \tag{47}$$

Where, $corcoef_{x,y}$ - correlation between x and y, avg_x - the average value of x and is given:

$$avg_x = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{48}$$

The dependence of the load on weather variables varies between winter and summer, as the trend towards electricity consumption changes as much on weekends and special holidays on the calendar. Therefore, the need to build different forecasting models for each season is a necessity to achieve maximum accuracy and efficiency in energy consumption.

Demand prediction error rate in artificial neural networks

The generalized rule is used to train the type of artificial neural network. The output vector is produced by representing the input network to the network. According to the difference between the received and target outputs, the weight of the network $\{Wij\}$ is adjusted to reduce the output error.

The error on the source layer propagates back to the hidden layer until it reaches the input layer. Due to the backward propagation of the error, the generalized delta rule is also called the error of the backpropagation algorithm.

The output of the neuron i, is is related to the input of the neuron j through the weight of the relationship Wij. If neuron k is not one of the input neurons, the state of neuron k is:

$$O_k = f\left(\sum_i W_{ik} O_i\right) \tag{49}$$

Where, $f\ (x)$ = 1 / (1 + e - x), and the sum is above all neurons of the adjacent layer. Let the target state of the original neuron be t. Thus, the error at the output of the neuron can be defined as:

$$E = \frac{1}{2}(t_k - O_k)^2 \tag{50}$$

Where, k - the output neuron.

The gradient descent algorithm adapts the scales according to the gradient error:

$$\Delta W_{ij} = -\frac{\partial E}{\partial O_j}\frac{\partial O_j}{\partial W_{ij}} \tag{51}$$

Specifically, we define the error signal as:

$$\partial_j = -\frac{\partial E}{\partial O_j} \tag{52}$$

With some manipulation, we can get the following generalized delta rule:

$$\Delta W_{ij} = \in \delta_j O_j \tag{53}$$

Where, $\in$ - an adaptation gain, δ_j - computed based on whether or not neuron j is in the output layer. If neuron one is one of the output neurons:

$$\delta_j = (t - O_j)O_j(1 - O_j) \tag{54}$$

If neuron not is not in the output layer:

$$\delta_j = O_j(1 - O_j)\sum_k \delta_k W_{jk} \tag{55}$$

To improve the convergence characteristics, we can enter the pulse term of the pulse gain α:

$$\Delta W_{ij}(n+1) = \in \delta_j O_i + a\Delta W_{ij(n)} \tag{56}$$

Where, n - an iteration.

Once the neural network is trained, it produces a very fast output for a given input.

To evaluate the results of the artificial neural network, you need to identify and characterize the percentage error:

$$error = \frac{|\,actual.load - forecasted.load\,|}{actual.load} \times 100 \tag{57}$$

General approaches to forecasting using neural networks

Data on the behavior of the object, the signs of which are associated with time, are presented as the results of observations in uniform time readings. For moments of time t = 1, 2, ..., n, the observation data take the form of a time series x (t1), x (t2), ..., x (tn).

Information about the value of the time series up to the moment n allows us to estimate the parameters x (tn + 1), x (n + 2), ..., x (n + m). The so-called "time window" method is widely used to predict time series elements.

Depending on the number of features that represent the values of the series in the formation of data sets, we distinguish two types of problems.

One - step forecasting

The one-step prediction problem is reduced to a mapping problem when one input vector is mapped to the output vector.

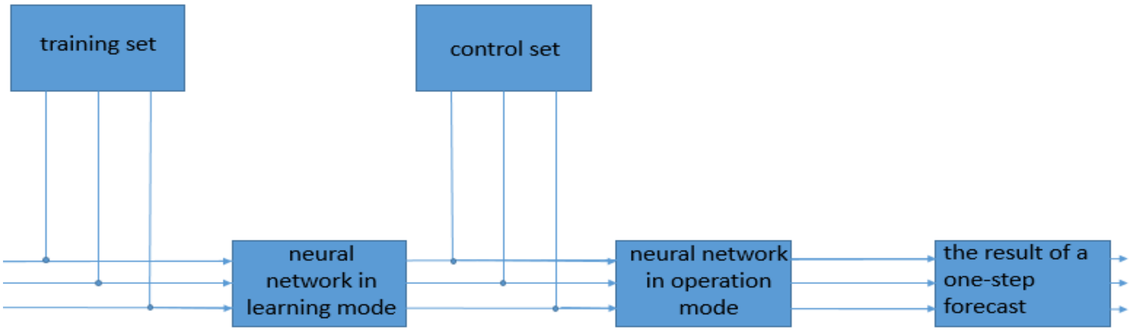


Figure 10. The sequence of using neural networks for forecasting.

In the case of a one-parameter prediction problem, the training set up to the moment n, provided m = 3, p = 1, s = 1.

Table 2. Training set for one-parameter prediction problem.

In			Out
$x(t_1)$	$x(t_2)$	$x(t_3)$	$x(t_4)$
$x(t_2)$	$x(t_3)$	$x(t_4)$	$x(t_5)$
…	….	….	…
$x(t_{n-3})$	$x(t_{n-2})$	$x(t_{n-1})$	$x(t_n)$

In the training mode, the coefficients of the weights of the connections are set, after which it becomes possible to switch to the operating mode. To predict the inputs of the neural network, the values of the last implementation of the training set are received $x(tn-2), x(tn-1), x(tn)$ The output is a predicted value $x(tn+1)$.

For a multiparameter prediction problem, vectors are given at the input of the neural network learning $x(tn-2), y(tn-2), z(tn-2), x(tn-1), y(tn-1), z(tn-1), x(tn), y(tn), z(tn)$ The outputs of the neural network receive the predicted values $x(tn+1),\ y(tn+1),\ z(tn+1)$.

The mode shown is single-step, which operates in display mode (real input and predicted output). Predictions are also used to model discrete sequences that are not time-related.

Given the specifics of time series, this type of forecast is not always appropriate, but for certain cases of short-term forecasts it is possible to use.

Multi-step forecasting

Multi-step forecasting is used only for phenomena whose signs are presented in the form of time series. During training, the network adjusts the weights of connections and polynomials of transfer functions, which in turn determine the mode of operation.

Multi-step time series forecasting is performed as follows:

A vector of known values is fed to the inputs of the neural network $x(tn-2), x(tn-1), x(tn),$ the output is a predicted value $x(tn+1)$ which determines the vector of predicted outputs and at the same time joins the values of the training set, is accepted as reliable.

Then the vector is fed to the inputs $x(tn-1), x(tn), x(tn+1),$ and the output is obtained $x(tn+2)$ and the following predicted values:

• For a multiparameter prediction problem, vectors are fed to the inputs of the trained neural network $x(tn-2), y(tn-2), z(tn-2), x(tn-1), y(tn-1), z(tn-1), x(tn), y(tn), z(tn),$

• The output produces values x*(tn+1), y*(tn+1), z*(tn+1), which form a vector of initial values and are sequentially attached to the values of the training set.

When the window is shifted to the forecast step, the output data produced by the network are perceived as real and participate in the prediction of the next value of the output, ie the inputs are fed to the vector $x(tn-1), y(tn-1), z(tn-1), x(tn), y(tn), z(tn), x(tn+1), y(tn+1), z(tn+1)$ and at the output we get $x1(tn+2),\ y1(tn+2),\ z1(tn+2)$ and the following predicted values.

Multi-step forecasting allows for long- and short- and medium-term forecasts, as the accumulation of error at each forecasting step has a significant impact on accuracy, but requires a highly trained and robust network that minimizes errors to the best value for forecasting.

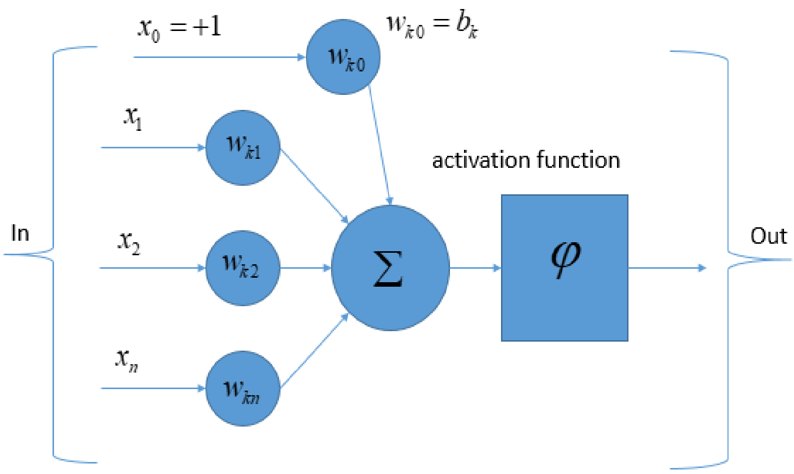


Figure 11. Neuron model in a multi-step prediction system.

Neutral Network with used in RBF techniques

The output of RBF neural networks is the estimated dependent load (in MW). In this method, the processing of the neuron input differs from other networks, where the pure input to the RBF transmission function is the vector distance between its weight vector and the input vector. The distance function used is a function of the weight of the Euclidean distance multiplied by the offset.

There are two types of RBF networks. In the first type, the number of neurons increases iteratively until the error of the square in the training process becomes lower than the target error. The second type is a precise radial basic structure that creates zero errors in training and produces neurons as much as the input vectors.

This type has various parameters that need to be adjusted. For this method, all parameters are related to the ANN architecture and network operation. The transfer function and the "logsigmoid" function have been adjusted to obtain a relatively low error.

In the RBF model, the reversals change and the error is measured after subtracting the predicted values. Four error rates were used to evaluate the prediction process: normalized root mean square error, mean absolute error, correlation and relative error rates:

1) Mean square error (MSE) and normalized root mean square error (NRMSE) are set:

$$MSE = \frac{1}{n} \times \sum_{i=1}^{n} (Y_i - Y_i^{\wedge})^2 \tag{58}$$

$$NRMSE = \frac{\sqrt{MSE}}{\frac{1}{n} \times \sum_{i=1}^{n} Y_i} \tag{59}$$

2) Average absolute error (MAE):

$$MAE = \frac{1}{n} \times \sum_{i=1}^{n} | Y_i - Y_i^{\wedge} | \tag{60}$$

The properties of MAE are as follows:

- Measures the average absolute deviation of the predicted values from the original.

- Also called Mean Absolute Deviation (MAD).

- Shows the amount of total error that occurred as a result of forecasting.

- In MAE, the impact of positive and negative errors is not negated.

- Unlike MFE, MAE does not give an idea of the direction of errors.

- For a good prognosis, the obtained MAE value should be as small as possible.

- Like MFE, MAE also depends on the scale of measurements and data conversion.

- Extreme forecast errors are not displayed in the MAE panel

3) Correlation index: determines the relationship between actual and projected load. Compared to the two previous indices, this index provides a more reliable indication of how the predicted load tracks the actual load in the load shape behavior:

$$corcoef_{x,y} = \frac{\sum_{i=1}^{n}(x_i - avg(x)) \times (y_i - avg(y))}{\sqrt{\sum_{i=1}^{n}(x_i - avg_x)^2 \times \sum_{i=1}^{n}(y_i - avg_y)^2}} \tag{61}$$

Where, $corcoef_{x,y}$ - correlation between x and y; avg_x - the average value of x.

4) The relative error (Re) between the two values:

$$R_e = \frac{Y_i - Y_i^{\wedge}}{Y_i} \tag{62}$$

Where, Y_i - Actual load value in MW for hour; $Y_i^{\wedge}$ - Predicted load value in MW for hour;

i - number of samples (hours).

Example of electrical load prediction based on RBF Neural Network Model

All prediction values and graphical images are based on neural models depending on the values of the error rates. The values are calculated in coefficients and then the perceptrons start the system of analysis and prediction.

The available data of the neural network of the Korean company were taken as an example, which, based on the RBF model, considered the forecasting of electricity using errors and the forecast of deviations from the actual values.

To model the system requires neural network equipment, which is programmed on Anaconda Python data with application libraries such as: NumPy, scikit-learn, Randas. TensorFlow. CUDA, Theano, Keras.

The effectiveness of the proposed method is assessed on the basis of a four-year data set provided by Korea (KPX). Three-year data from January 2014 to December 2017 are used to study RBF models and to identify error correction gains. The load curve is predicted for one year of data to assess the accuracy of the studied models and error correction.

The best design parameters for RBFN models are found by searching the grid, which executes more than 60 to 95 neurons and 1 to 15 propagation values with grid pitch points of 1 and 0.1, respectively.

The use of day types for the next forecast day to enter variables significantly reduces the error, as shown in Table 3. The forecast deviations from the actual values are calculated using the equation:

$$MAPE = \frac{1}{D}\int_{t=1}^{D}\{\frac{1}{N}\int_{i=1}^{N}\frac{|L_{a,t}^{i} - L_{p,t}^{i}|}{L_{a,t}^{i}}\times 100\} \tag{63}$$

$L_{a,t}^{i}$ and $L_{p,t}^{i}$ are the actual and forecast values of the load curve, respectively, N is the number of the hours of the day i.e., N = 24, and D is the number of the forecasted days.

Maximum absolute percentage error (MAP) calculated using the equation:

$$MAP = \max\{\frac{1}{D}\int_{t=1}^{D}[\frac{1}{N}\int_{i=1}^{N}\frac{|L_{a,t}^{i} - L_{p,t}^{i}|}{L_{a,t}^{i}}\times 100]\} \tag{64}$$

Example iinitial data for forecasting

The minimum and maximum errors for RBFN1, and the minimum and maximum errors for RBFN2 are reduced. Figure 9 and 10 shows the predicted result for 8 days from Saturday to next Monday, including special holidays.

Our results show that the use of the next day type is effective for predicting the workload curve on the working day before the holidays.

Table 3. Design parameters for RBFN models.

Model	Hour	Parameters	
		No. of neurons	Spread
RBF 1	1	92	13.7
	2	91	13.2
	3	92	12.8
	4	82	13.2
	5	91	12.5
	6	84	15.3
	7	82	10.5
	8	82	11.5
	9	76	10.8
	10	88	14.6

	11	65	12.4
	12	77	11.8
	13	93	13.8
	14	77	13.5
	15	70	12.3
	16	78	14.3
	17	77	11.9
	18	72	11.1
	19	90	13.1
	20	75	12.0
	22	91	11.3
	23	86	13.9
	24	67	14.9
RBF 2	1-24	74	14.8

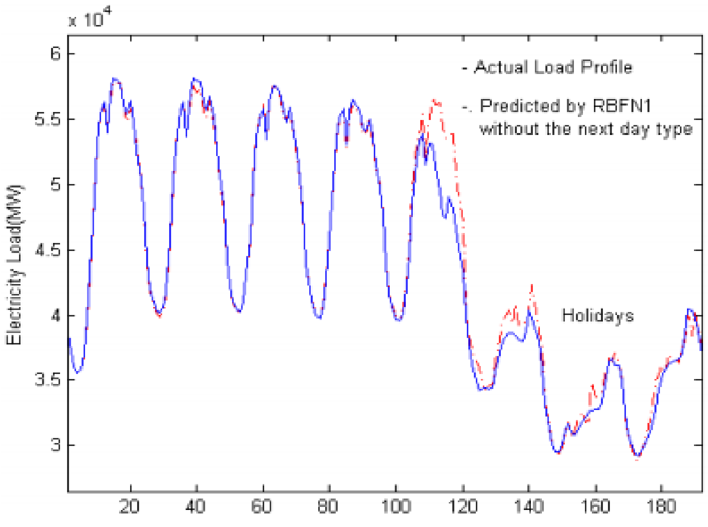


Figure 12. Load curve forecast with special holidays. Next day type is not used in RBFN1.

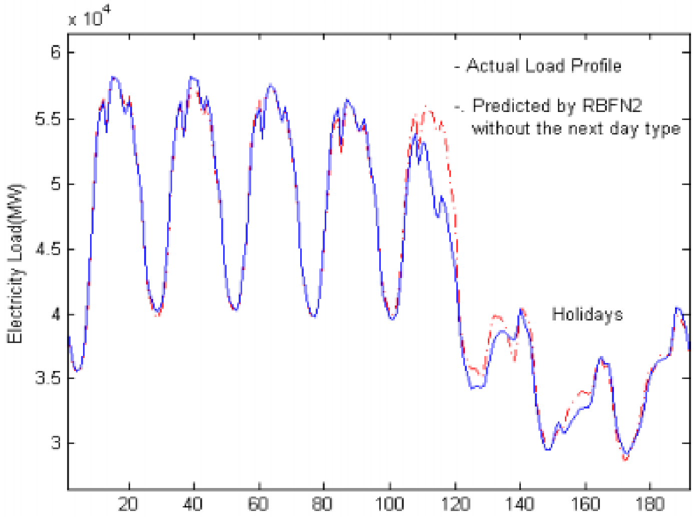


Figure 13. Load curve forecast with special holidays. Next day type is not used in RBFN2.

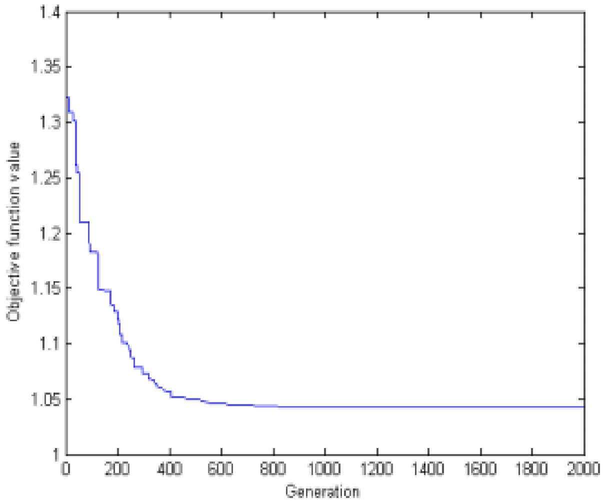


Figure 14. Forecast error during the evolutionary search of gains. RBFNEC1, radial basis function neural network.

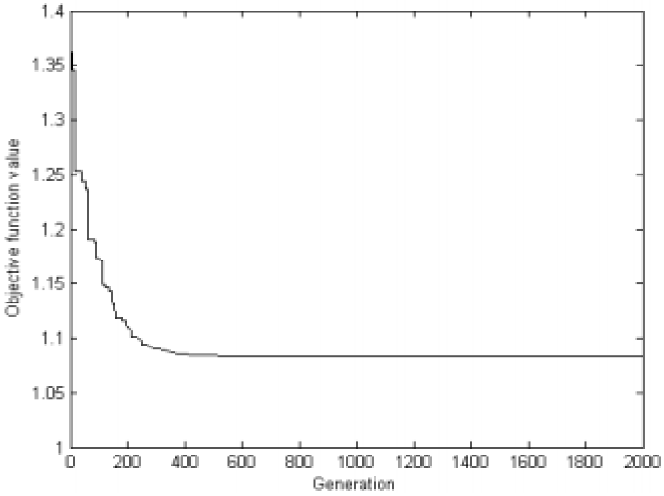


Figure 15. Forecast error during the evolutionary search of gains. RBFNEC2, radial basis function neural network.

Table 4. Influence of day type on the forecast of the next day.

Error	Day type	RBFN1		RBFN2	
		Train	Test	Train	Test
MAPE	No use	1.143	1.227	1.153	1.334
	Use	1.048	1.156	1.087	1.234
MAP	No use	23.74	26.00	18.56	16.43
	Use	18.49	15.85	17.29	14.75

For the best error correction 48 coefficients 24 kp and 24 kd minimization (4) is sought using DE. For differential evolution, the following control parameters are used: population size = 20, maximum generation = 2000, differential gain = 0,5, and crossover speed = 0,5.

Table 5. Optimal gain for error correction.

Hour	RBFNEC1		RBFNEC2	
h	kp	kd	kp	kd
1	0.0765	0.0669	0.2194	0.0904
2	0.1312	0.0567	0.2011	0.0861
3	0.0983	0.0547	0.1741	0.0932
4	0.0579	-0.0034	0.1911	0.0872
5	-0.0043	0.0160	0.1154	0.0592
6	-0.0250	0.0669	0.0369	0.0525
7	0.0427	0.0548	0.0107	0.0263
8	0.0958	0.0650	0.1251	0.0722
9	0.1607	0.0828	0.1485	0.0720
10	0.1438	0.0778	0.1864	0.0703
11	0.1162	0.0984	0.1232	0.0522
12	0.1067	0.0965	0.1171	0.0572
13	0.0690	0.0676	0.0921	0.0717
14	0.1093	0.0478	0.0905	0.0429

15	0.1073	0.0702	0.0551	-0.0011
16	0.1343	0.0419	0.0745	0.0110
17	0.1055	0.0351	0.0294	0.0048
18	0.0385	0.0125	-0.0164	0.0075
19	0.0045	0.0018	0.0351	0.0218
20	0.0949	0.0613	0.0055	-0.0032
21	-0.0455	-0.0074	0.0121	-0.0009
22	-0.0407	-0.0430	-0.0736	-0.0357
23	-0.0038	-0.0182	0.0015	-0.0138
24	0.0040	-0.0041	-0.0528	-0.0321

Peak load prediction errors are shown in Table 5, which shows that the correction reduces both MAPE and SE. The results of load prediction from RBFNEC1 and RBFNEC2 are shown in Figure 14 and 15. Figure 16 and 17 shows that the correction reduces the SE by less than one-ninth at the end of the test year.

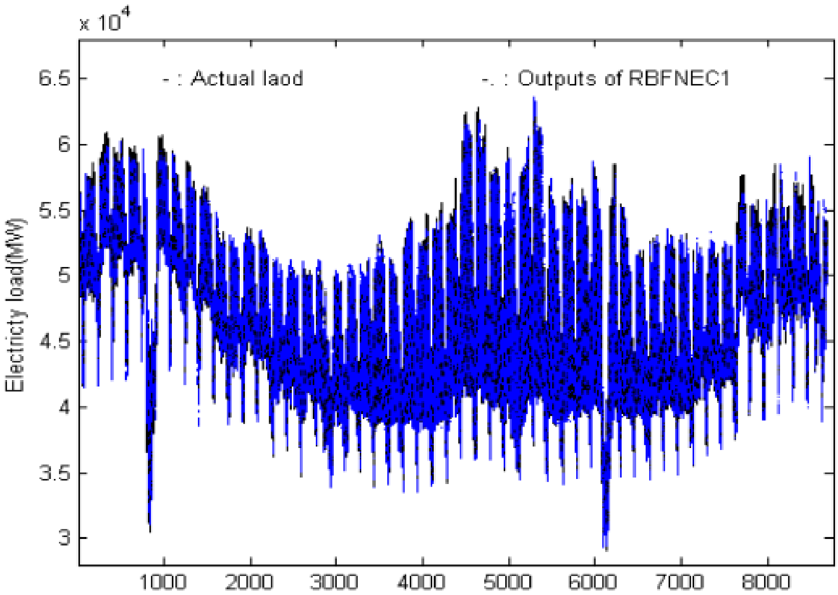


Figure 16. Day-ahead load curve forecasts used for the evaluation. RBFNEC1.

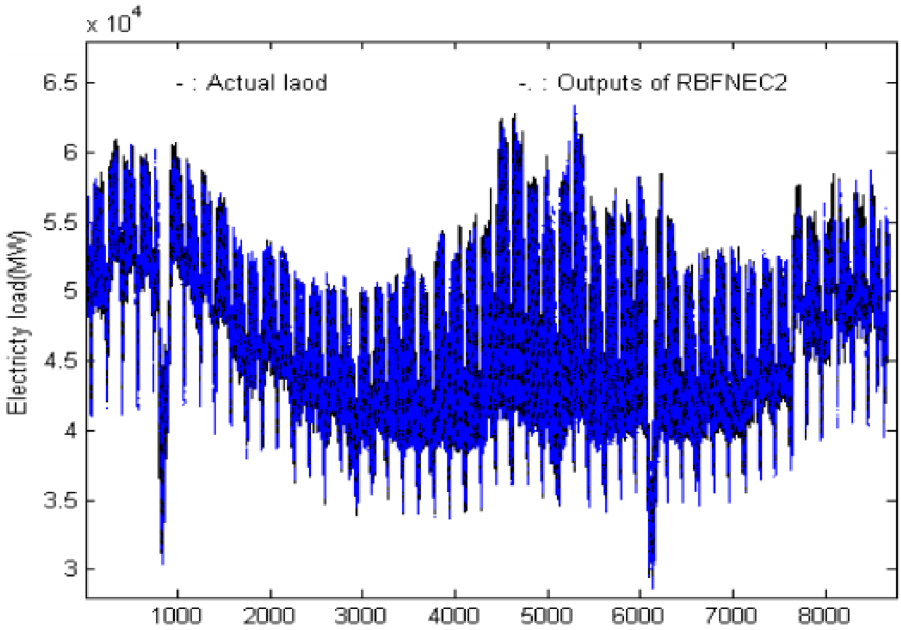


Figure 17. Day-ahead load curve forecasts used for the evaluation. RBFNEC2.

This part presents an example of a method for predicting the load curve forward combining the RBFN model with the error correction method. To distinguish the download of the same day from the rest of the data field, the RBFN model includes the type of day to the next day in the forecast, except for the previous and the day of the forecast as its input variables.

Developed an RBF model based on the optimal number of neurons and propagation, which are found by searching the grid. Proportional and identifiable derivative coefficients for the best error correction by differential evolution.

The RBFN model is also corrected by adding a linear combination of a 24-hour load curve and coefficients. The coefficients are optimized to minimize MAPE and SE errors in DE. The results of the experiments show that the RBF model combined with the error correction method produces accurate load curves and peak load predictions and is reliable for weather and seasonal changes.

Table 6. Peak load forecasting errors.

Proposed method	Learning	Testing	Learning	Testing
	MAPE	SE	MAPE	SE
From load curve	1.142	76063	1.298	73112
After correction	1.192	7208	1.284	-7446

MAPE - mean absolute percent error; SE, sum of errors.

This method can be implemented in real time with hourly or daily receipts for adaptation and updating based on changing conditions.

With the advent of new technologies, the universe is paying more and more attention to modern technologies. Static methods and others are already outdated methods that have errors in measurement data and inaccurate processing of the original data. With the advent of MicroGrid, SmartGrig, neural networks have found their place in today's forecasting markets. This is a new stage of development that has a future.

Forecasting electrical load is a rather complex process. All optimal modes of the power system are calculated on the basis of forecasts. Learning and developing a neural network is quite expensive in terms of computing resources. There is a problem of "oversaturation" during neural network training. Therefore, it is necessary at the initial stage to "process" the network and create resistance to unpredictable negative situations and consequences of data processing. The system has training vectors that ensure the development of the system. Experiments with neural networks show that the learning architecture is quite fast. This is due to the development of multi-agent systems, where each agent performs his work and role in the system. Hardware agents can be both stand-alone and combined. Combined agents are created by coordinating agents who perform observations.

Neural networks will adequately respond to change with the help of these agents. New processing and forecasting models are based on new computer programming systems, various visualization methods through application libraries and C ++-based programs, etc. This allows you to accurately and quickly describe the values and parameters of the system data.

Conclusion for 2 question

To date, a popular factor in the power system has been the introduction of artificial intelligence based on robotic artificial intelligence, which is close to human. The development of a neural network for forecasting electricity consumption, methods of decision tree was presented. The formulas for the figures on the structure of the neural network are given. The system should provide process automation, forecasting of automation processes, decision-making processes without human intervention and, above all, timely response to the detection of negative factors. Ability to make optimal and fast decisions that minimize the harmful factor to zero. Provide the process of management and control of the power system for uninterrupted monitoring. Encoding and decoding of streaming information nodes. Dependent data protection.

Visual data about the program based on a neural network in China's largest power industry is borrowed. Shows how a neural network system is able to compute and solve complex mathematical data to optimize maximum efficiency.

The classification of neuronal errors is considered. Each neuron must undergo a training course from the previous neuron to be able to predict independently in the future.

Forecasting on this method is the most modern method for 2020. This is the best method for forecasting energy consumption, but it is quite difficult for countries that cannot progress on artificial intelligence technologies.

3. DEFINITION OF CONSUMPTION ALGORITHMS AND OPTIMAL FUNCTIONING IN LOCAL SYSTEMS

3.1 Balance and generation monitoring in local systems

The analysis of the peculiarities of the functioning of local power supply systems with flexible generation and active agents, the peculiarities of the functioning of the MAS at the local level is investigated. Definition of algorithms and optimal functioning of local systems with flexible generation and active consumers. The need to consider this issue is the ability to manage and adjust electricity consumption schedules, in conjunction with generation. The main activity of this issue is to solve the individual problem of managing the demand for optimal consumption of the object and the consideration of optimal generation. The task is based on the use of prosumers as consumers of electricity and determining the load schedule in various technological processes, which are associated with algorithms for optimal operation of local systems with flexible generation.

Traditionally, energy monitoring systems are created and used both for individual installations, units and their small groups, and for entire technological processes. At any production facility, the number of technological installations is measured in hundreds or even thousands. There is a potential need for energy monitoring to build hundreds of relevant systems, which is time consuming and costly. And the feasibility of these costs is not always obvious.

The choice of individual technological installations, their groups or technological processes for which it is possible and expedient to create local energy monitoring systems is a rather difficult task. This task must be solved "individually" for each production facility.

At the first stage, all the main and auxiliary equipment of the enterprise should first be divided into a certain, relatively small number of groups. It is most expedient to carry out such distribution on the technological principle. That is, the available technological equipment should be distributed between the technological processes of production of all types of products of the enterprise. To this end, first of all, it is necessary to draw up diagrams of relevant technological processes, which should reflect the sequence of individual operations and the relationship between them. As well as information about the equipment on which these operations are performed, indicating the types of energy consumed.

The next step in solving the problem should be to build balances of energy consumption separately for each of the technological processes of production of all types of products of the enterprise.

In addition, the construction of optimal calculation models of electric balances can be used to compile balances of electricity consumption in the production processes of each type of product.

On the basis of the constructed balances of energy consumption and the made technological schemes the actual volumes of energy consumption for the previous periods at the enterprise can be reasonably distributed between all types of production.

Thus, it is possible to obtain statistics on energy consumption for the production of each type of product, which are necessary in the subsequent stages of identifying local technological facilities to create an energy monitoring system at the enterprise.

The next step in solving this problem should be the division of the main and auxiliary equipment, related to the technological process of production of each type of product, into smaller groups. Such further grouping of equipment should be carried out on the basis of two criteria:

- The first of these criteria should be the location of the relevant equipment in certain buildings, structures or production facilities.
- The second criterion for further grouping of technological equipment of the enterprise should be the schemes of internal energy supply of the relevant buildings, structures and production facilities.

Such an analysis, in turn, requires a number of additional tasks. The main tasks are:

- Determination of the composition of factors (parameters of the technological process, external conditions, etc.) that affect the amount of energy consumption by each of the pre-defined groups of equipment;
- Determination of additional energy metering devices, production, as well as parameters that characterize the production conditions required to build an energy monitoring system for each of the equipment groups;
- Assessment of monetary costs for the construction and operation of such an energy monitoring system;
- Assessment of the energy saving potential that will occur due to the creation of an energy monitoring system covering each group of equipment under consideration;
- Financial analysis of the feasibility of creating an energy monitoring system for pre-defined groups of equipment.

For this site, using different methods, several options for building an energy monitoring system were selected. Consider using ABC analysis to solve the problem.

This analysis is based on the grouping of objects according to their significance and specificity. You must first select a sample of objects that would be united by a common feature. For example, this may be the amount of energy consumption of each type of equipment of a separate production unit. In the future, the total amount of energy consumption for the production unit as a whole is calculated:

$$w_{sum} = w_1 + w_2 + ... + w_n, \tag{62}$$

Where, $w_1 + w_2 + ... + w_n$ - annual energy consumption of a separate "n" object of the production; n - is the corresponding number object production.

This analysis is based on the grouping of objects by their significance and specificity. You must first select a sample of objects that would be joined by a common object. For example, this may be the amount of energy consumption of each type of equipment of a separate production unit.

$$K_n = \frac{W_n}{W_{sum}} \cdot 100\% \tag{63}$$

$$K_z = K_n + K_{n+1}, \% \tag{64}$$

To build balances of electricity consumption at production facilities in conditions of insufficient and unclear initial data on the values of technological parameters, indicators of production conditions, as well as electricity consumption, when the use of traditional calculation and analytical method is almost impossible, you should use probability theory and mathematical statistics.

General principles of application of the probabilistic-statistical approach to construction of balances of consumption of electric energy in the specified conditions.

The presence at the production facilities of numerous and diverse equipment that operates in different modes, the complexity and consequences of technological processes significantly complicate the procedure for building electrical balances. To simplify this task, it is proposed to apply a hierarchical approach, which involves its consistent solution first by product type, and then by units involved in the production process of each product type.

The most difficult case of construction of electric balances is the scheme with the uniform initial information of volume of consumption of the electric power at the enterprise as a whole, and also technological schemes of manufacture of each kind of production. Under these conditions, to find the energy consumption of individual units use a simplified calculation and analytical formula:

$$W_i = P_{all} k_z T_i \tag{65}$$

Where, де P_{all} – installed capacity of the i-th unit of equipment;

k_z – the average load factor of this equipment;

T_i – duration of its work.

The numerical values of the quantities k_z та T_i , are usually unknown or vaguely defined parameters. Therefore, the first step in building electrical balances in these conditions is to determine the most probable values of indicators k_z and T_i

Electrobalance

The task of determining the unknown structure of the cost part of the electricity balance by type of product is to find the most probable values of electricity consumption for the production of each type of product.

It is proposed to search for such values by solving an optimization problem, the objective function and constraints of which have the form:

$$Z = \prod_{i=1}^{n} f(W_i^{np}) \to \max \tag{66}$$

$$W_{i\min}^{np} \le W_i^{np} \le W_{i\max}^{np} \tag{67}$$

$$\sum_{i=1}^{n} W_i^{np} = W^{pd} \tag{68}$$

Where, $f(W_i^{np})$ – the probability of occurrence of a certain value of electricity consumption for the production of the i-th type of product, determined by the relevant distribution law;

W_i^{np} – possible volume of electricity consumption for the production of the i-th type of product (change of optimization);

W^{pd} – the total amount of electricity consumption at the enterprise, known from commercial accounting data.

The next step is to determine the cost parts of the balance for the units involved in the production of each product, which is carried out by solving a number of optimization problems with the following target functions and constraints:

$$Z = \prod_{i=1}^{n} f(W_i^{np}) \to \max \tag{69}$$

$$W_{i\min}^{dl} \le W_i^{dl} \le W_{i\max}^{dl} \tag{70}$$

$$\sum_{i=1}^{n} W_i^{d} = W^{np} \tag{71}$$

Where, $f(W_i^{dl})$ – the probability of occurrence of a certain amount of electricity consumption of the i-th unit, determined by the relevant distribution law;

W_i^{dl} – possible volumes of electricity consumption by the i-th unit (optimization variable);

W^{dl} – the most probable value of electricity consumption for the production of the i-th type of product, determined as a result of the construction of the electric balance by type of product.

Thus, electric balances by types of products and units, built using probabilistic and statistical methods based on data only on the actual volume of electricity consumption at the production facility as a whole, compared with the balances obtained by calculation and analytical methods, are more reasonable and reliable, as they are based on the data of additional sample observations or on the results of a survey of relevant experts, as well as on the established laws of distribution of vaguely defined indicators.

Electric balance and production

However, in most industrial facilities, in addition to accounting for total electricity consumption, there is also accounting for production volumes, which creates more favorable conditions for the construction of electricity balances.

In this case, the solution of this problem begins with the construction of a preliminary balance for the types of products that can be obtained by constructing a linear multifactor mathematical model:

$$W = b_1 Q_1 + b_2 Q_2 + ... + b_n Q_n \tag{72}$$

Where, W – total electricity consumption according to commercial accounting data;

$Q_1, Q_2 \dots Q_n$ – production volumes of each type,

$b_1\, b_2 \dots b_n$ - coefficients of the regression equation.

For the numerical values of the coefficients of the model by known statistical methods can be set certain intervals, the physical content of which is the range of possible values of the specific consumption of electricity for the production of each product.

The following certain intervals are defined by expressions:

$$[d_{i.\min} = d_i - t(a, n-m) s_{di}; \tag{73}$$

$$d_{i.\max} = d_i + t(a, n-m) s_{d_i}\,]; \tag{74}$$

Where, d_i – the value of the i-th coefficient of the regression model;

$t(a, n-m)$ – the distribution coefficient for the bilateral probability D and the number of degrees of n – m - 1;

n – the amount of data in the sample;

m – the number of independent variables in the mathematical model;

s_{di} – the standard deviation of the values of the corresponding regression coefficient.

Thus, the proposed approach to the construction of electricity balances and production facilities allows for known actual volumes of electricity consumption and production to obtain much more reliable and reasonable balances for products, as they are additionally based on the construction and use of adequate mathematical models of dependence between production volumes. products and volumes of electricity consumption.

At some production facilities, there is a situation where all technological processes are known to have analytical relationships between the volume of electricity or energy consumption, production volumes and other technological parameters. The presence of these dependencies, in principle, already makes it possible to build a sufficiently reliable and sound electrical balances using the calculation and analytical method.

In addition, the construction of sufficiently reliable and reliable electrical balances of production capacity using the proposed probabilistic-statistical approach allows to obtain separately for each unit or process the estimated statistics of their electricity consumption required for operational control of electricity efficiency by relevant technological facilities.

Dispersed generation in the network

When integrating of renewable energy sources (RES) into distribution electric networks (DENs), the issue of optimal control of modes of such networks, in particular, voltage regulation in case of load change and generation in the electrical system, becomes relevant. The value of voltage, as one of the main indicators of electricity quality in electrical distribution networks, is regulated by GOST 13109-97.

It is noted that in normal mode to maintain the voltage within acceptable limits can be used SDG or additional compensating devices. Therefore, the issue of optimal voltage regulation in power distribution networks with distributed generation sources is very important and requires careful study.

There are several approaches to solving the problem of optimal control of modes in the electricity distribution network with distributed generation sources.

For example, the issues of integrated management of normal and post-emergency modes of power supply systems with SDG are considered. Control of normal modes in this case is based on ensuring a minimum of power losses in the network:

$$\sum_{l \in L} R_{lk} I_{lk}^2 \to \min \quad k \in K \tag{75}$$

Where, K — the number of considered normal modes;

L — number of branches in the network;

R_{lk}, I_{lk}^{2} — active resistance and current in the branch l for mode k.

The algorithm for controlling post-emergency modes is aimed at ensuring a minimum energy deficit:

$$\sum_{n\in N} P_{nk} - \sum_{n^*\in N^*} P_{n^* j} \rightarrow \min, k \in K, j \in J \tag{76}$$

Where, J — the number of considered post-emergency modes in case of loss of the main power supply;

P_{nk} — loading in node n in normal mode k;

$P_{n^* j}$ — load in node n* in post-emergency mode j part of the network, which includes N* nodes;

N — number of nodes.

At the same time, compliance with the restrictions on the levels of voltages and currents of the network is checked. This approach requires the addition of a target function to track losses caused by the operation of distributed generation sources themselves and to take into account the deterioration of electricity quality due to voltage deviations in the distribution network.

The goal is to maximize the output power of the SDG:

$$P_{Ga} \rightarrow max \tag{77}$$

taking into account the power balance:

$$\begin{aligned} P_{Gi} - P_{Di} - Pi(V,\theta,t) = 0 \\ Q_{Gi} - Q_{Di} - Q_i(V,\theta,t) = 0 \end{aligned} \tag{78}$$

and restrictions:

$$\begin{aligned} & t = t(V); \\ & Q_{Ga} \le Q_{Ga} \le \bar{Q}_{Ga}; \\ & \underline{V} \le V_i \le \bar{V}; \\ & (i = 1, 2, ..., NB), \end{aligned} \tag{79}$$

Where, P_{Gi}, Q_{Gi} — output active and reactive power SDG;

P_{Di}, Q_{Di} — active and reactive power consumption.

Dispersed grid generation and renewable energy sources

Particular difficulties arise in optimizing the operation of wind (WPPs) and solar power plants (SPPs), as their modes are determined by the stochastic influence of the environment. The mathematical expectation of their total active power is:

$$M_{SUM(t)} = M_{WPP}(P(t)) + M_{SPP}(P(t)). \tag{80}$$

3.2 System with technological processes with active consumption and dispersed generation of energy resources

The control system is a set of technical means necessary for the operational management of the power plant (substations), ie for conducting the technological process with the specified technical and economic indicators.

The control system contains five main groups of devices (subsystems):

- regulation;
- management of executive bodies;
- alarms;
- measurement;
- protection.

Measurement and signaling subsystems provide the necessary information about the operation of the equipment and the flow of the technological process, and with the help of control and management subsystems actively influence, ie control the object. At sharp deviations from the set normal mode or at damage of the equipment protection works and carries out automatic shutdown of the corresponding elements.

The choice of control system depends on the characteristics of the projected object (type of station and its equipment, structure of technological connections, level of automation of technological process), the accepted organizational structure of operational control, as well as the level of development of control systems.

The control system has the ability to control one or more systems of the technological process. The technological process may change depending on changes in a number of basic characteristics, namely:

- Change of parameters P, U, I, f, according to time characteristic;
- Change / scheduling of workload according to pricing with the influence of time characteristics;
- Introduction of operating modes in accordance with pricing with the influence of time characteristics.

Load schedules are divided into:

- Individual - for each individual type of technological process;
- Group - combined types of technological processes.

Depending on the change of these parameters, the losses of the technological process also depend. They can be maximum, normalized, minimal. Electricity consumption is influenced by the following factors:

- Production technology;
- External conditions of production;
- Organization of production;
- Technological condition of the equipment.

Sealing the load schedule allows the power system to:

- Reduce capital expenditures needed to provide consumers with the required amount of electricity;
- Reduce the specific fuel consumption for the production of 1 kwh and the requirements for maneuverability of power equipment;
- Increase the return on capital of the industry, reduce the capital intensity of electricity production, improve operating conditions;
- Reduce the amount of harmful emissions from electricity generation and the cost of its generation.

The main goal - control of technological processes and the ability to change modes of operation. According to the modes, there are different categories of equipment that are sensitive to changes in network parameters and characteristics.

Therefore, it is necessary to clearly determine the appropriateness of changing the parameters of the grid and predicting whether the process system can change the "conditions" and "work in other conditions" without critical moments.

The set of managed objects and parameters must interact with each other. If you change the parameters that are critical to the process, the grid will cause a number of negative factors, namely:

- Equipment overload
- System instability
- Lower voltage below the level, which is a critical characteristic
- Malfunction of control equipment

The change in the installed capacity depends on the time and on the pricing of the load schedule in a specific period of time (days / weeks). Depending on the usability of the power, we can increase or decrease the power.

It is necessary to forecast for the day ahead so that there is no "undersaturation" of power electricity.

Energy monitoring of the control system should carefully assess the possibility of changing the parameters of the technological load to minimize future projected, planned projected and unscheduled projected losses.

Load planning is based on the total (summary) energy consumption, which remains unchanged. You can change the power according to the time characteristic, which has convenience and reliability.

Electricity consumption is divided into:

- uniform consumption of electicity;
- uneven consumption of electicity.

The nature of the consumed active P and reactive energy Q during the period of time under consideration T may be different. Active P and reactive energy Q in the calculated interval T has the form:

$$\begin{aligned} active_P &= P \cdot t \\ reactive_P &= Q \cdot t \end{aligned} \tag{81}$$

If the energy consumption occurs at a constant value of current I, and the line resistance is equal, the energy loss during this period will be:

$$\Delta active_{P(I)} = 2R_{line} I^2 T \tag{82}$$

That is, they will be twice as large, although cosφ = 0.8 in all cases has the same value. This example confirms that the traditional power factor does not take into account uneven consumption. The current value of cosφ = 0.8 depends on the active and reactive power, which can constantly change depending on the mode of operation of the consumer:

$$tg\varphi = Q / P, \cos\varphi = P / s = p / (P^2 - Q^2)^{-1/2} \tag{83}$$

Depending on the average value of cosφ T, which is determined by the following expression:

$$tg\varphi = reactive_P / active_p \tag{84}$$

$$\cos\varphi = \frac{active_p}{\sqrt{active_p^2 + reactive_p^2}} \tag{85}$$

Currents in one system can cause the consumption of the same active power P, which is usually accompanied by the transfer to the consumer of reactive power Q, pulsating power Sb, latent power So and distortion power D. The current value of the power factor in the new sense is expressed:

$$\lambda = \sqrt{\left(\frac{\Delta P_{\min}}{\Delta P}\right)} = \sqrt{\left(\frac{\sum I^2}{\sum I^2}\right)} \tag{86}$$

For the same types of consumption and active energy, this ratio is:

$$\lambda_T = \cos_{\varphi_T} = \frac{\sqrt{active_p^2 + reactive_p^2}}{\sqrt{A\left(U^2\right)}\sqrt{A\left(I^2\right)}} \tag{87}$$

Thus, the traditional power factor $\cos_{\varphi_T}$ corresponds only to the uniform nature of electricity consumption in the undistorted system and is a special case of the factor λ_T .

If the consumption during the entire control period T is uniform:

$$\begin{aligned} U_A &= U_B = U_C = U \\ I_A &= I_B = I_C = I \\ \varphi_A &= \varphi_B = \varphi_C = \varphi \end{aligned} \tag{88}$$

The average value of electricity consumption within the same tariff zones of different electricity load schedules will coincide. The total cost of electricity consumed per day of these different load schedules will also be equal to:

$$\begin{aligned} \Delta W^1_{night} &= \Delta W^2_{night} \\ \Delta W^1_{day} &= \Delta W^2_{day} \end{aligned} \tag{89}$$

Any uneven consumption of the company's load schedules is smoothed out by a large number of other consumers, but the total capacity remains unchanged.

Non-uniformity of power system load schedules is characterized by the coefficient of non-uniformity, which varies depending on the season, day of the week and other factors:

$$\alpha = \frac{P_{\min}}{P_{\max}} \tag{90}$$

Where, Pmin i Pmax – respectively the minimum and maximum electrical load.

If there is a deviation in the network, then the standard deviation, also called the standard, is defined as:

$$\sigma p = \sqrt{P^2_{sc} - p^2_c} \tag{91}$$

Accordingly, the smaller the difference between the square root mean square value of electricity consumed and the square of its mean value, the smaller the unevenness of the schedule of electrical loads:

$$\mathrm{p(t) = p = const} \tag{92}$$

Load schedule form factor:

$$k_f = \frac{p_{sc}}{p_c} \tag{93}$$

The maximum coefficient as well as the filling factor characterize the ratio of the hourly maximum load and the average value of the graph in relation to each other:

$$k_M = \frac{P_{\max}}{P_c}, k_z = \frac{P_c}{P_{\max}} \tag{94}$$

The smaller the difference between the maximum value of consumption and its average value, the greater will be the coefficients of maximum and filling up to 1.

The coefficient of non-uniformity characterizes the ratio of the minimum value of the load to the maximum:

$$k_n = \frac{P_{\min}}{P_{\max}} \tag{95}$$

The smaller the difference between the maximum value of consumption and the minimum, the greater the coefficient of non-uniformity will go to 1. At Pmax = Pmin , $p(t) = p = const$.

Thus, the criterion of uniformity of electric load graphs from the point of view of classical evaluation coefficients can be represented as follows:

$$\begin{cases} \delta \to 0; \\ K_f \to 0; \\ K_M \to 0; \\ K_z \to 1; \\ K_n \to 1. \end{cases} \tag{96}$$

These conditions will become unchanged during the time of electricity consumption:

$p(t) = p = const$.

It is obvious that the problem of estimating the non-uniformity of electric load schedules and the task of managing (or equalizing) the non-uniformity of electric load schedules are links of one circuit.

In order to effectively regulate power supply schedules, it is necessary to clearly understand the nature of non-uniformity of power supply schedules, to give a complete and objective assessment of this non-uniformity.

In addition, the very essence of the criterion of uniformity of electricity schedules according to the classical theory of non-uniformity, contradicts the approach of management by tariff zones, when the criterion of uniformity of electricity schedules is determined by enterprises based on economic indicators of daily schedules of electricity.

The calculation of optimal modes of power supply systems should be carried out using models of electricity sources and electricity consumers, which take into account both technical, economic and socio-environmental indicators and parameters of the modes.

The presence of own sources of active and reactive power in the power supply systems of an industrial enterprise determines the development of an algorithm that allows to obtain the optimal distribution of active and reactive power between units of own power plants according to the minimum cost of electricity consumed by the enterprise.

It is expedient to optimize the modes of power supply systems also by the amount of loading of own power plants by reactive power and by the position of control branches of transformers of closed networks.

Power consumption management and optimization of power supply systems requires determining the regulatory effects of group loads, as well as identifying the impact of static characteristics of consumers and capacitors on power and voltage losses in the passive elements of power supply systems.

It is also necessary to determine the influence of the degree of reactive power compensation in the power networks and voltage levels in the nodes of the power supply system on the power consumption from the power supply. To make the analysis of dependences of the specified factors on parameters of elements of electric networks and consumers.

It is also advisable to optimize the consumption of active power from the power supply in the interconnected determination of voltage levels in the power supply systems of industrial enterprises and the power of capacitors in the shop networks.

The system contains two objects that have the consumption and generation of active capacity of the enterprise. Consumption and generation can be compatible or different. It depends on the operation of the technological process and the parameters of the power grid.

Objects perform a certain technological work / process, which depends on:

- The complexity of the process, which in the future will affect the technical characteristics
- Changing / compiling a load schedule according to pricing with the influence of time characteristics
- Change of parameters P, U, I, f to time characteristics

Each technological process has its own operating conditions and modes of operation. The consumption of each facility must ensure the reliability and quality of energy consumption.

The system must have a control body that is responsible for controlling technological processes, characterization of energy consumption and generation. Appropriate conditions for these technological objects must have appropriate control.

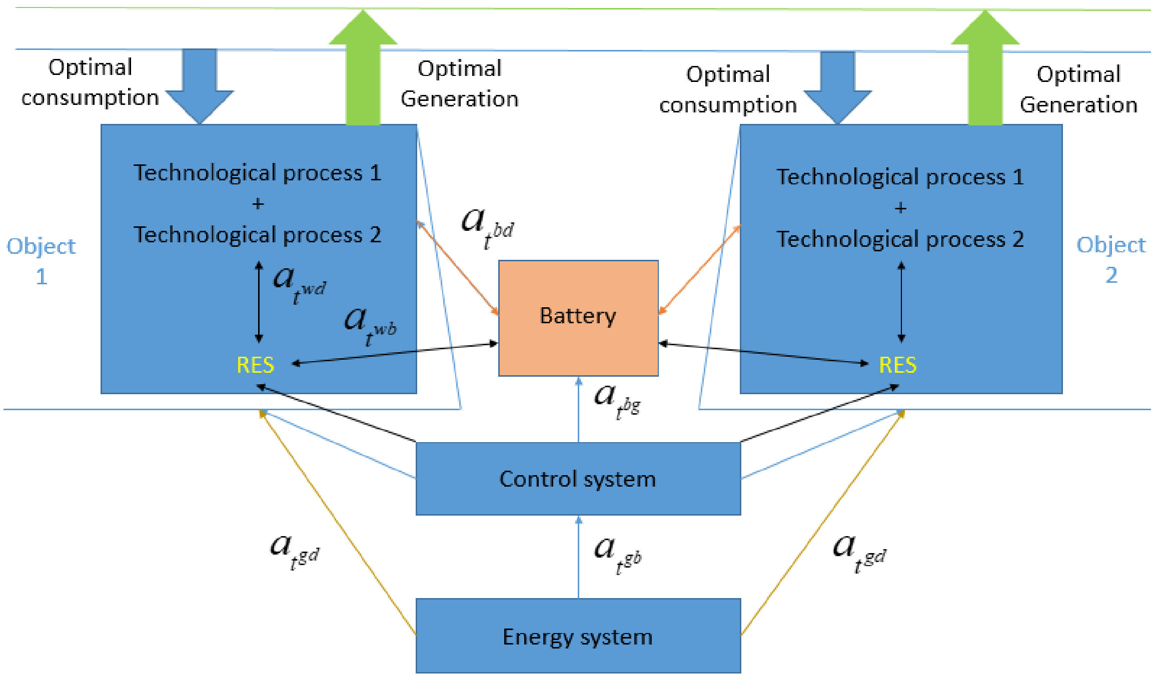


Figure 18. System of optimal consumption and generation.

Where, $a_{t^{gd}}$ - technological connection of control between the power system and the object of technological processes;

$a_{t^{gb}}$ - technological connection of control between the power system and the control system;

$a_{t^{bg}}$ - technological control connection between the control system and the battery;

$a_{t^{wb}}$ - technological connection of control between the system of renewable energy sources and the battery;

$a_{t^{wd}}$ - technological connection of control between technological processes and renewable energy sources;

$a_{t^{bd}}$ - technological control relationship between technological processes and the battery.

$$a_t = (a_{t^{wd}}, a_{t^{gd}}, a_{t^{bd}}, a_{t^{wb}}, a_{t^{gb}}, a_{t^{bg}})^{\tau} \geq 0, a_t \in x_t \tag{97}$$

$a_t = a_{t^{bd}} + a_{t^{gd}} = D_t$ - the amount of energy in general

$a_{t^{bd}} + a_{t^{bg}} \leq B_t$ - the amount of energy in the battery

Consumption has the ability to adjust and regulate energy consumption parameters. Increasing consumption requires increasing the reliability of system supply.

Distribution network operators are forced to increase their efficiency due to consumers who demand better services and regulatory procedures established by regulatory authorities.

There may be different groups of electrical receivers in two facilities, so the approach of the need to regulate the technological process must be treated with a clear position of safety.

Also, the introduction of distributed generation sources in electrical networks can reduce the environmental impact on the environment and solve many problems associated with emissions and waste from production.

The introduction of such a source can provide:

- Reducing the cost of electricity. This is a positive factor for the object as a whole.
- Unloading the system and ensuring the process of modernization of facilities.

All these aspects will diversify future risks that may have an impact on rising electricity prices.

Generation technology is based on:

- Combustion of fuel, which is subsequently converted into energy.
- Production of energy (active energy) from energy sources.

Such generation technology can be based (located) near the end users of electricity to ensure the economic efficiency of the distribution network. Generation can have both positive and negative effects.

The first is the process of influencing the voltage level in the established modes of operation of the power grid. Secondly - the influence of distribution generation on voltage frequency fluctuations in power grids.

In power grids, active and reactive loads change in nodes under the influence of time, which causes certain fluctuations in voltage levels in the network. Therefore, it is customary to analyze the effect of voltage, the effect on losses and higher harmonics.

3.3 Algorithm for selection of characteristics of optimal energy consumption

Uneven graphs of the electrical load of the power system complicate the balance of consumption and prevent changes in the frequency of the AC network and the calculated voltage level.

Due to the technological requirements of generating stations, it is impossible to quickly and optimally clearly cover the graphs of electrical loads of the power system at each point of its day. This leads to significant losses on the use of natural resources in the generation of electricity.

The power system load graphs is the sum of many consumer load schedules, so you can only align the graphs with the help of consumers - regulators who are able to limit, adjust or transfer their electrical load from one time of day to another, as for daily regulation.

The main goal is to provide economic incentives for the company to regulate electricity consumption from more stressful periods to / from less busy ones.

Flexibility must be in place to create space for balancing the power system and to be able to reduce the limitations of renewable generation while reducing dependence on coal generation.

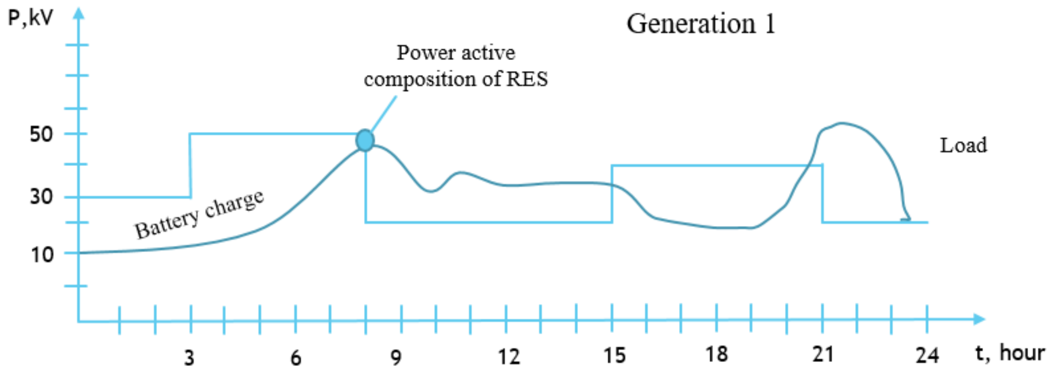


Figure 19. Flexibility of consumption and generation of the power system 1.

The use of batteries as an additional power source allows to increase the energy autonomy of the wind farm and increase the share of RES use in distribution networks.

The use of the energy storage element in the RES requires the development of new improved control methods taking into account the parameters of the energy storage element and the load of consumption.

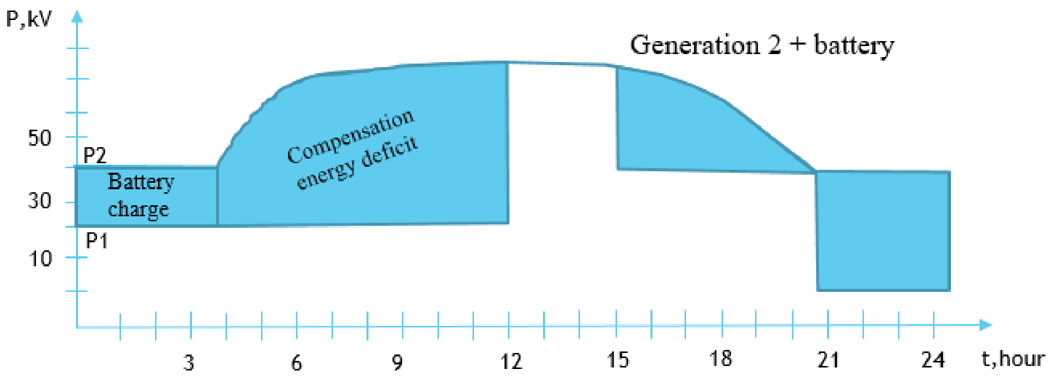


Figure 20. Flexibility of consumption and generation of the power system 2.

If RES stations produce a certain amount of energy during a certain period of time, which is greater than the load, it is necessary to accumulate it in order to ensure electromagnetic compatibility in the network.

The control unit must respond in a timely manner to any changes that may be caused by changes in energy needs. The use of the battery in the structure of RES will significantly improve the stability of work and provide full, or partial, coverage of consumer needs in times of adverse conditions.

The introduction of renewable energy sources in energy systems reduces the use of natural resources, as well as reduces the harmful effects on the environment associated with pollution from waste generated during electricity generation. RES, in particular solar, cannot cover the morning according to the evening load schedule. The operation of solar RES depends solely on solar activity. In turn, the season also actively influences the level of electricity production.

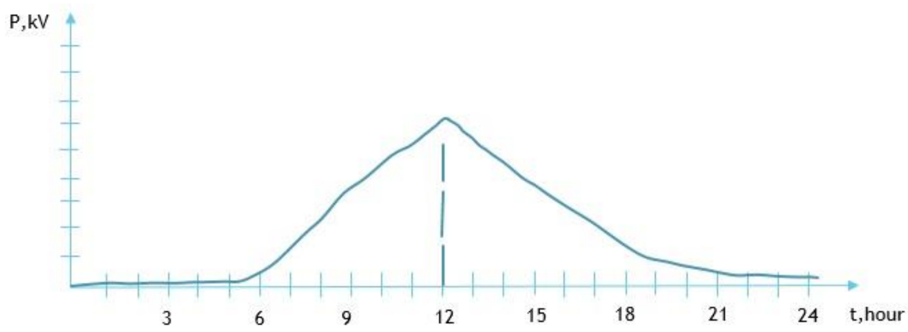


Figure 21. Time characteristics of RES.

Given the operation of RES in the power grid, it is obvious that the definition and implementation of control effects to ensure optimal modes and their joint operation, in accordance with changes in external influences, is possible only with an autonomous control system.

The introduction of distributed energy sources and generation, like any technical measure, requires an assessment of technical and economic efficiency. One of the integrated indicators of the operation of electrical networks with DRG is the electricity received from DRG during the calculation period. This indicator depends on the type of primary energy resource and the method of obtaining electricity.

$$W_{RES} = \sum_{i=1}^{N} \sum_{j=1}^{M} (W_{\Pi_{ij}^{teor}} - \Delta W_{ij}^{N}) \eta_{G_j} \qquad (98)$$

Where, i – Type of primary energy resource; j – serial number of the generation node;

$W_{\Pi_{ij}^{teor}}$ - the share of energy of the primary energy resource that can be used for electricity generation in the node "j" RES.

ΔW_{ij}^{N} - the share of energy of the primary resource of type "i", which for some technological reasons was not used in node "j" (RES shutdown, power control).

η_{G_j} - The efficiency of the node "j" generation.

Electricity can be divided into two streams:

- Our consumption $W_{\text{actually}_{\Sigma}}$
- Generation in the power system $W_{G_{\Sigma}}$

$$W_{ESys_{\Sigma}} : W_{G_{\Sigma}} = W_{Actually_{\Sigma}} + W_{ESys_{\Sigma}} \tag{99}$$

From the standpoint of modernization, the introduction of RES into electricity allows to increase the cost, but at the same time in terms of overall efficiency of electrical networks, there are a number of problems related to RES, in terms of electricity quality, electricity losses, operation of relay protection devices and automation. An important factor is the overall impact of RES on total load schedules.

graph form factor:

$$K_f = \sqrt{\frac{\sum_{i}^{24} (P_i - P_G)^2}{24 \cdot P^2_{\text{average}}}} \tag{100}$$

Where, i – serial number of the hour; P_i - active power in the network for the “I” time interval before the installed RES; P_G - active power of RES; $P^2_{average}$ - average daily active power of the network after the installation of RES.

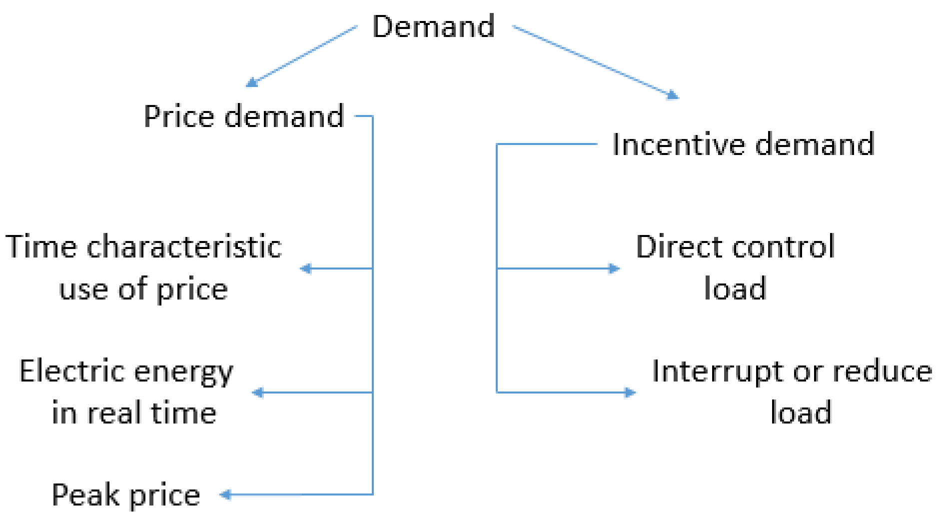


Figure 22. Demand of technological process

In our case, in order to manage and be able to regulate, optimize the schedule of electrical load consumption, we must adapt such characteristics as:

- Temporal characteristics of dependence
- Price characteristics of dependence
- Power from the time characteristic of the dependence.

Because generation is a process that is difficult to adjust and depends on geothermal environmental conditions.

As a result, generation can work simultaneously or sequentially to reduce "failures" in generation. After that, it is possible to reduce the consumption of electricity from the grid. During normal loads, generation can accumulate in the battery for further use in the company's own technological needs.

An example of share of the energy characteristic in a certain time characteristic:

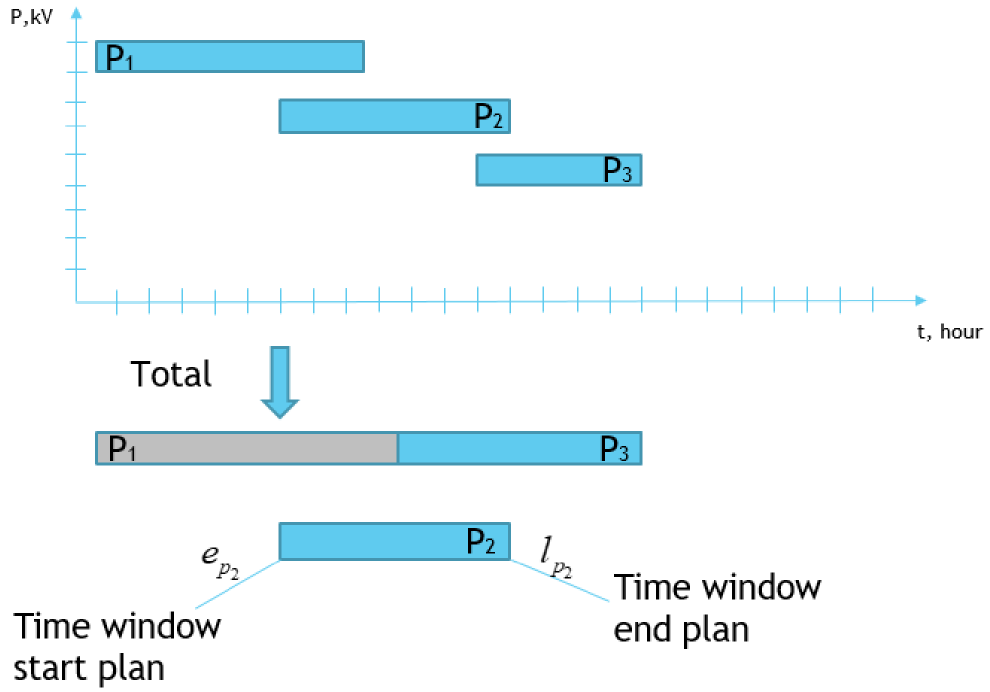


Figure 23. Time division of power characteristics.

If we need the amount of start and end, then the start plans and charging rates are indicated:

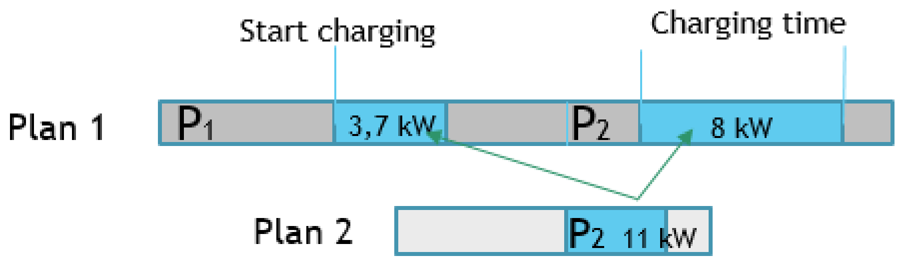


Figure 24. Two phases of solving the problem of photovoltaics.

The relationship of time characteristics is developed in three stages.

1. At the beginning, we accept the time characteristic that we can change:

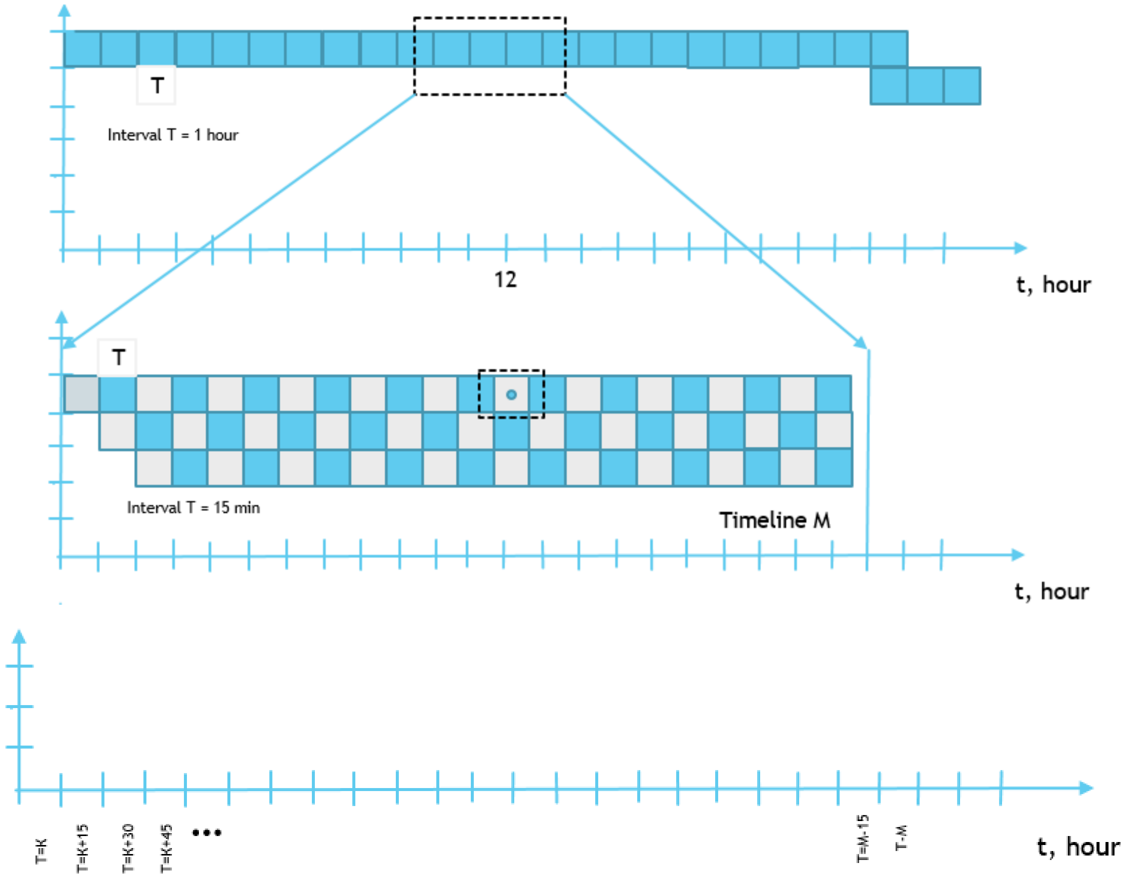


Figure 25. Separation of time characteristics

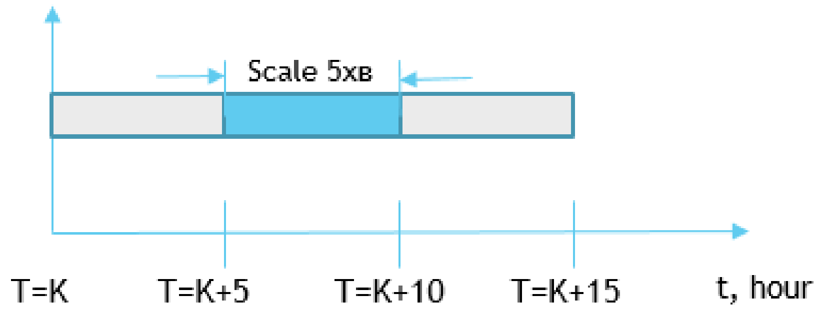


Figure 26. Division of time characteristics.

Power consumption charts can be adjusted in time intervals "t", if appropriate.

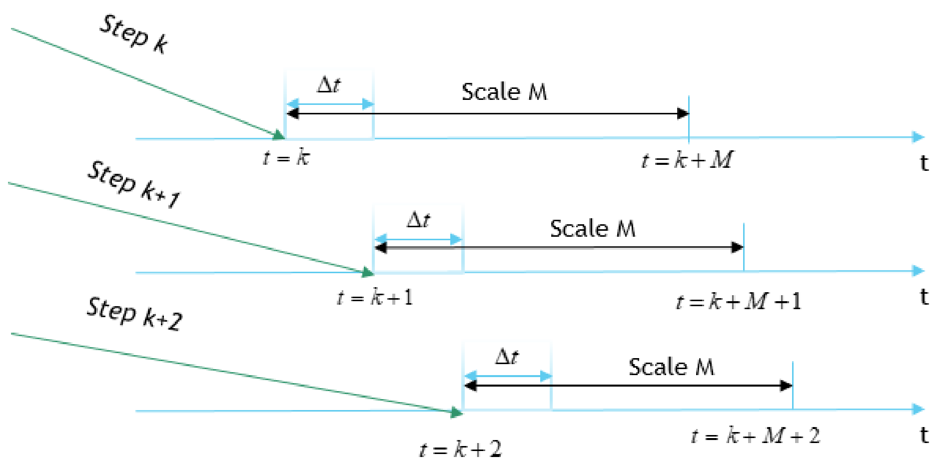


Figure 27. Division of time characteristics into parts M

1) If we have our own generation, then in times of peak load we can reduce the consumption of electricity from the grid and use the consumption of the battery (ensuring the generation of energy from the RES).

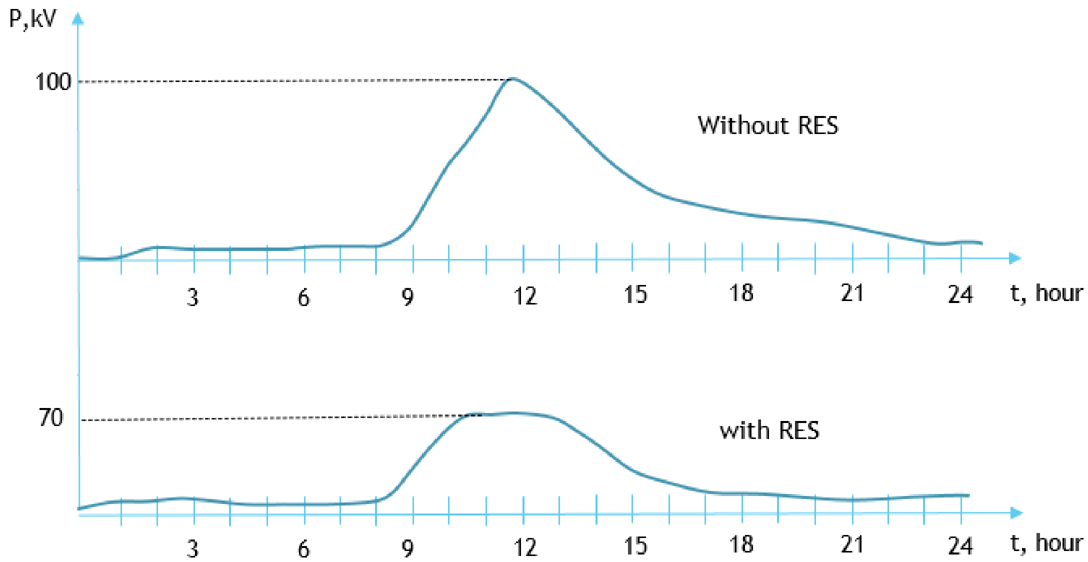


Figure 28. Dependence of consumption with the use of RES.

If it is possible to change the technological process depending on the time and price characteristics:

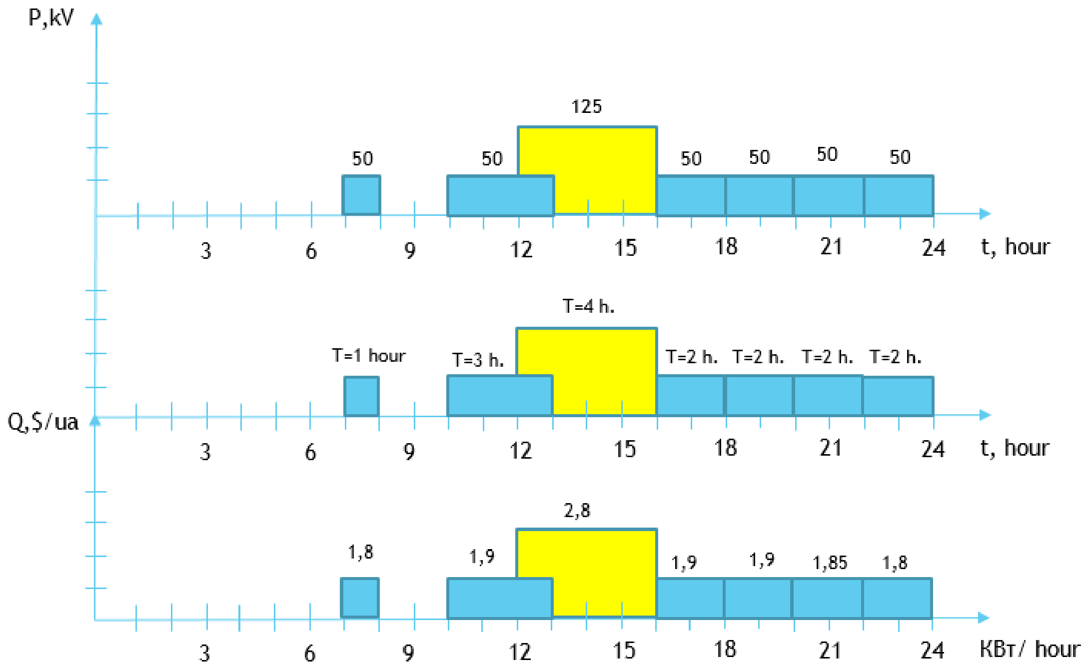


Figure 29. Dependence of the installed capacity on the time characteristic with the established price characteristic.

Depending on the time, we can change the time of switching on / commissioning of the electrical installation of the technological process and be able to adjust.

It is impossible to change the pricing of the network, so the best solution is to review the price market and create a schedule for the operation of electrical equipment. It is also possible to change the power by combining technological processes at one time or another on the schedule.

<u>In order to choose a strategy for production, which in the future should meet the needs, it is necessary to build an algorithm for the interaction of optimal modes of operation of the power system:</u>

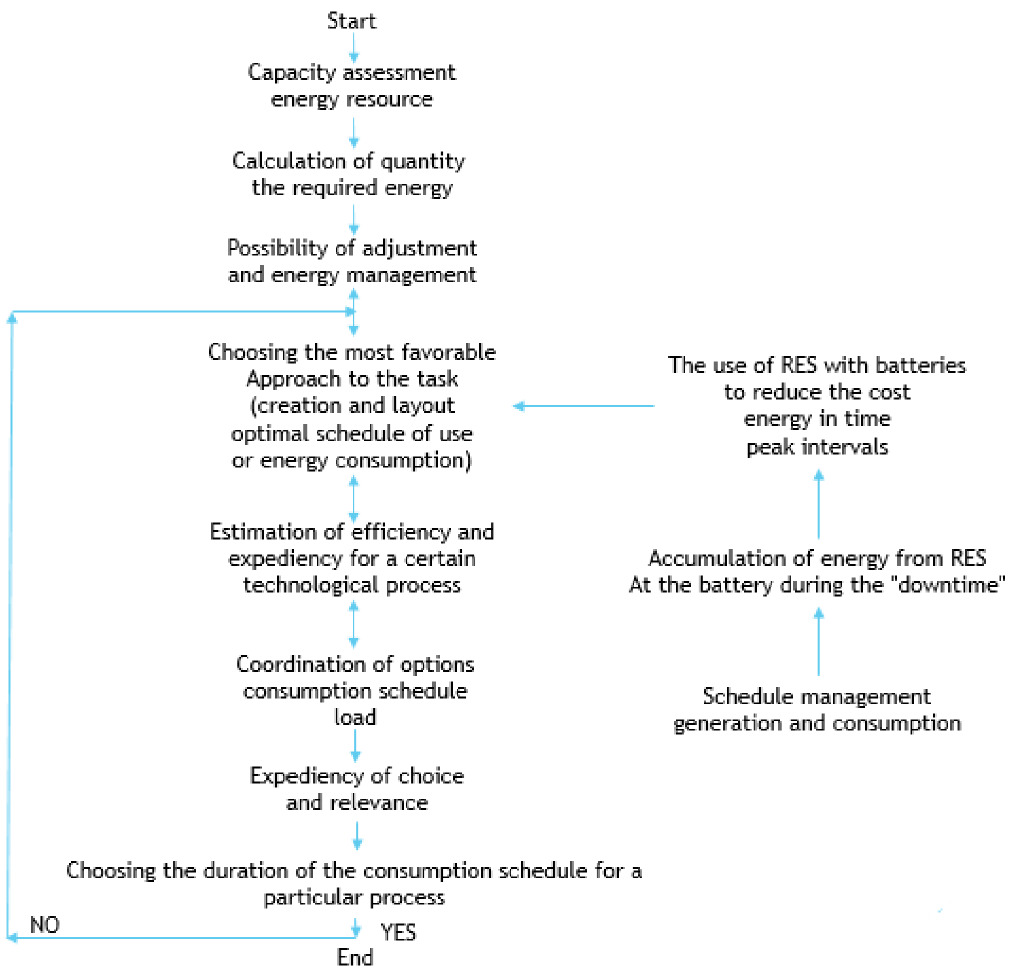


Figure 30. Algorithm for selecting the optimal schedule of energy consumption.

Step 1. Capacity assessment energy resource.

The presence of all generations, adjacent parts of energy consumption is indicated. These characteristics of power, voltage, current are set for further monitoring.

Step 2. Calculation of quantity the required energy.

The required amount of energy for the technological process with the specified generation is specified in order to have optimization, uninterrupted and reliable power supply.

Step 3. Possibility of adjustment and energy management.

Effective power grid management measures are being introduced. Control devices of the whole system and control devices for this control are introduced.

Step 4. Choosing the most favorable approach to the task (creation and layout optimal schedule of use or energy consumption).

Creating a primary schedule of energy use. A schedule is created for the day ahead, for its further modernization.

Step 4.1 Parallel Choosing The use of RES with batteries to reduce the cost energy in time peak intervals.

The choice of RES equipment is important to ensure its own generation at the enterprise. The equipment must be compatible with the existing power grid system.

Step 4.2 Accumulation of energy from RES at the battery during the "downtime".

Energy must have a capacity to store energy that is excess. This energy can be used in the future for the company's own needs in the field of economics.

Step 4.3 Schedule management generation and consumption.

The consumption and generation schedule is optimized. It is necessary to clearly imagine the possibility of reducing consumption from the network and increasing consumption from own generation

Step 5. Estimation of efficiency and expediency for a certain technological process.

Personnel to assess the effectiveness and feasibility should calculate all the indicators for the choice of consumption scheme of the enterprise and be able to improve.

Step 6. Coordination of options consumption schedule load.

At this stage, agree on the optimal consumption schedule for the company.

Step 7. Expediency of choice and relevance.

At this stage, the correct choice of consumption schedule is determined. All future shortcomings in energy consumption are anticipated.

Step 8. Choosing the duration of the consumption schedule for a particular process

The schedule must be agreed by the project managers. The duration of the consumption schedule depends on the nature of the technological process. The technological process should be with the maximum loaded efficiency factor.

following these algorithms, we decide whether to meet the system's consumption needs. If not - the algorithm must be selected in the appropriate sequence

Given the algorithm for selecting the optimal schedule of energy consumption, we can offer 3 optimal consumption options:

1. Combined - groups of power consumers operating in parallel in a certain interval t

2. Continual - groups of power consumers operating sequentially in a certain interval t

3. Corrective - groups of power consumers operating depending on the specified conditional time and price characteristics.

Option 1 – Combined

If it is possible to adjust the technical process in another period of time, we use this option to save money. During the generation of “T” = 6-9 hour, we can use energy for consumption (to reduce network consumption) or save it in the "battery" for future use.

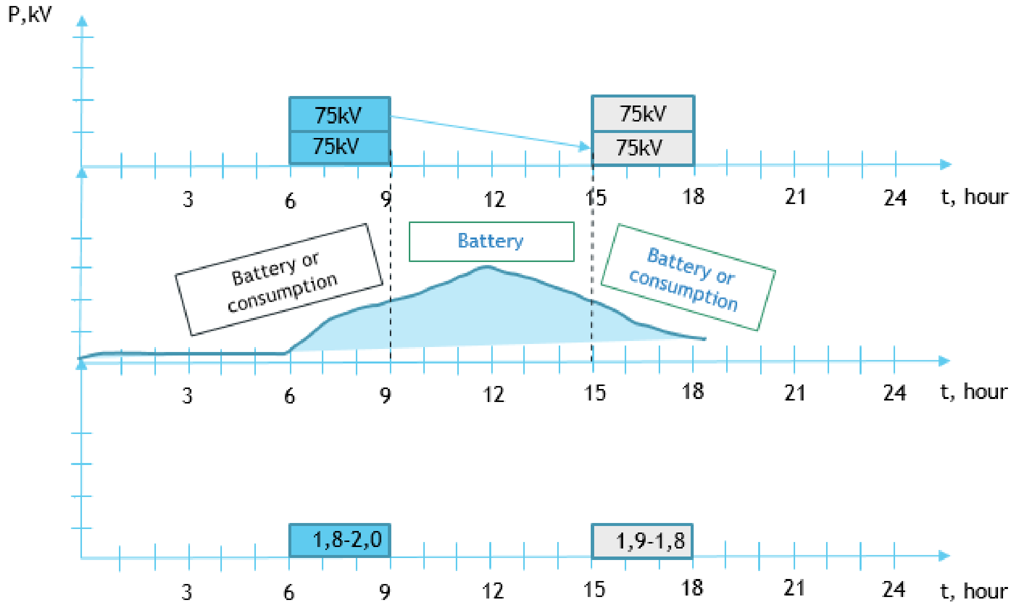


Figure 31. Combined energy transfer with the possibility of "transfer".

Option 2 - Continual

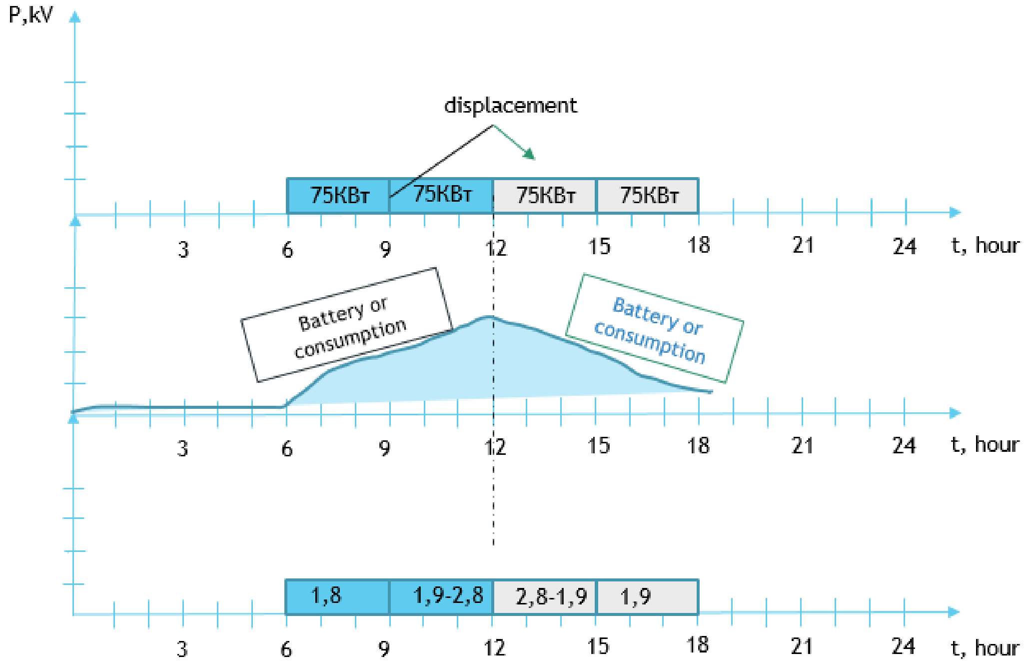


Figure 32. Continual energy consumption with the possibility of "transfer".

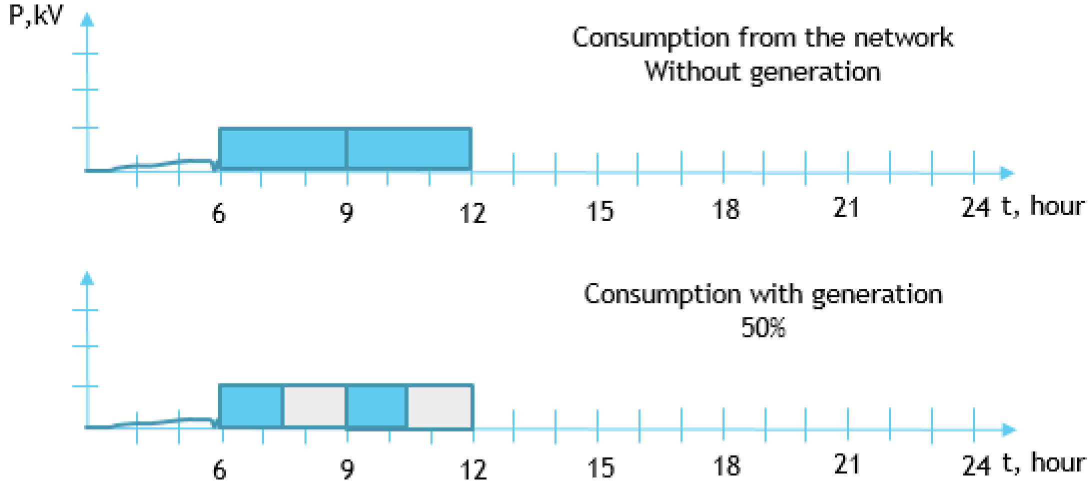


Figure 33. Consistent energy consumption with the possibility of consumption from RES by 50%.

If we shift the technological process, then depending on this, the price of energy from the network changes. Because we have generation, we can reduce power consumption and use our own consumption. The price can be reduced in case of reduction of consumption from the power grid.

Option 3 – Corrective

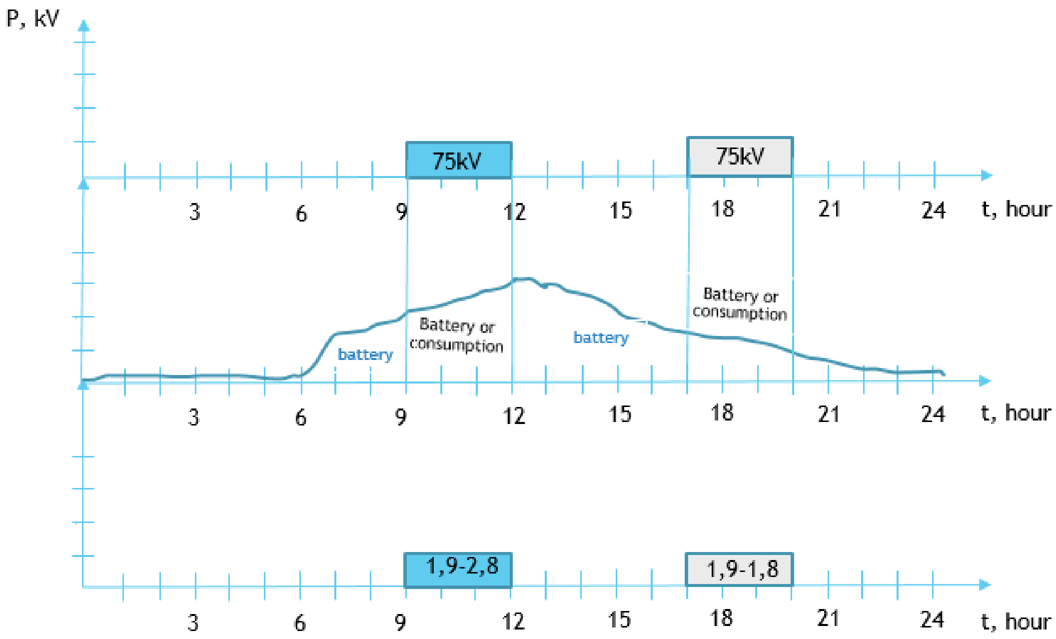


Figure 34. Application of consumption at a certain selective point in time.

Technical processes are divided into 2 time periods, which have different pricing. With peak times, we can generate and store energy until it is used. The price depends on the time, but it can be reduced by using energy from the battery for own consumption.

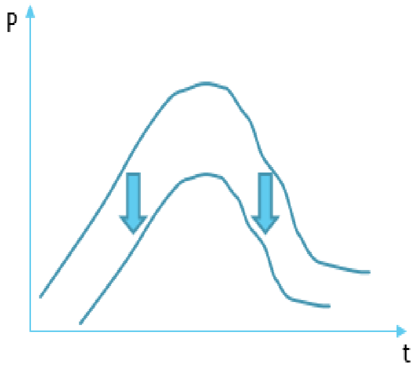
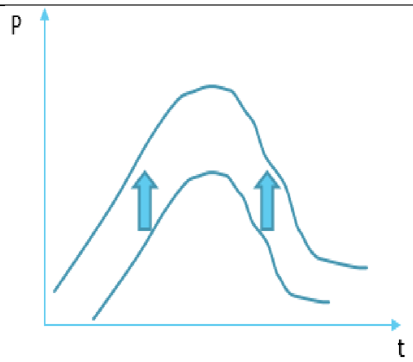
Table 7. The algorithm is expressed in a mathematical sense.

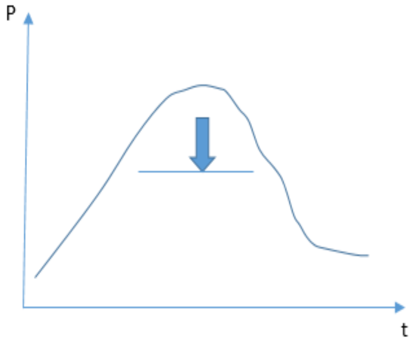
The total power of the entire interval	$P_{sum} = P_{start} \bullet \Delta t_1 + P_{end} \bullet \Delta t_2 ; kV$
Total energy consumed from the line	$W_{all} = \dfrac{P_{sum1} + P_{sum2}}{T} ; kV$
If the technological process occurs at different intervals, it is necessary to use the average value:	$U_{average} = \dfrac{U_1 t_u + U_2 (T - t_u)}{T}$ $I_{average} = \dfrac{I_1 t_1 + I_2 (T - t_1)}{T}$ $P_{aver.} = I_{aver.} \bullet U_{aver.}$
If consumption is equal	$\Delta U = \Delta I = \Delta$ (proportional increase in power growth) $P^2 = U_1^2 I_1^2 (\delta + \Delta^2 (1 - \delta))$
If there are two identical intervals	$t_1 = t_2 = t$

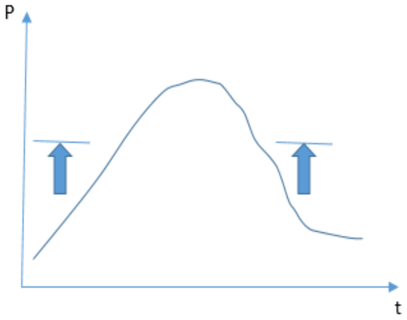
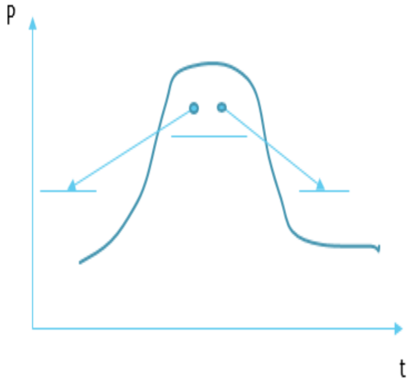
	$t_1 + t_2 = T$ $P = \frac{U_1 I_1 t}{T_t} + \left(\frac{(U_1 + \Delta U)(I_1 \bullet \Delta I)(T_t - t}{T_t} \right)$
Battery generation and energy	
Power consumption from the network	$P_{G(t)} = P_{Load(t)}$
Power consumption and battery system from the network	$P_{G(t)} = P_{Load(t)} + P_{battery(t)}$
Power consumption from the mains and / or from the battery	$P_{Load(t)} = P_{G(t)} + P_{battery(t)}$
Pricing	
The value of the share of energy from the grid for consumption (without generation and battery)	$Wline_1 = \frac{P_{sum}}{t}$ Total energy consumed over time
The value of the share of energy from the grid for consumption (with generation and battery)	$Wline_2 = \frac{P_{sum} - P_{gener.} - P_{battery}}{T}$
Energy price per unit of product	$Q_{all1} = Q_{line} \cdot W_{all(t)}$
(without generation)	
Energy price per unit of product (from generation)	$Q_{all2} = Q_{line} \bullet W_{all(t)} - W_G$
Mains consumption with storage of energy in the accumulator	$Q_{all3} = \frac{Qline \bullet W_{all(t)} + W_{battery}}{T}$
The cost of energy can be adjusted, depending on the generation	$Qline_1 = Q_{all} - Q_{W_G}$ (reduced price for technology)
	$Qline_2 = Q_{all} + Q_{W_G}$ (price for total consumption + battery charge)
	$Qline_3 = W_{all} \bullet Q_{line} \bullet t$
Price per battery charge from the network	$Q_{W_{battery}} = Q_{line} \bullet t$

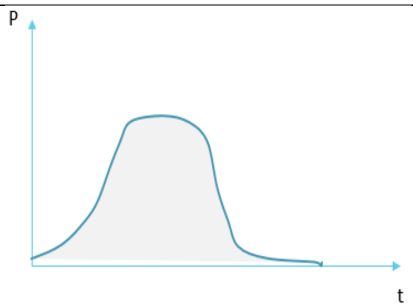
3.4 Energy saving measures in the mathematical model

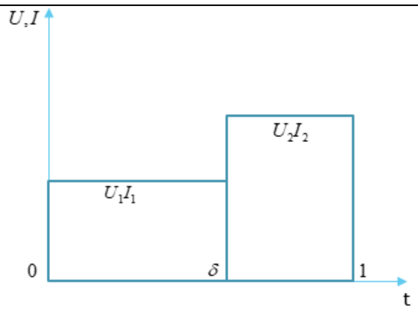
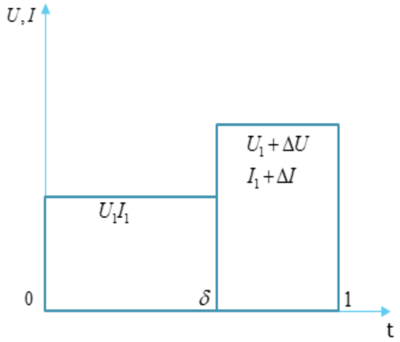
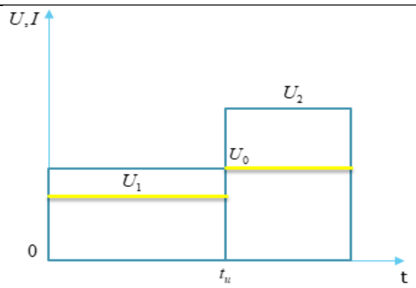
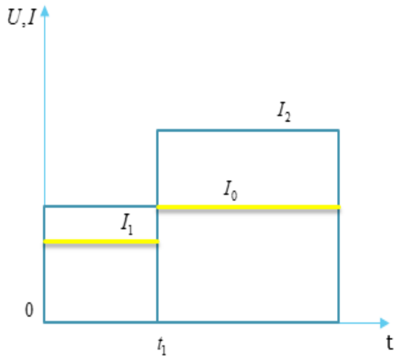
Table 8. Energy saving measures.

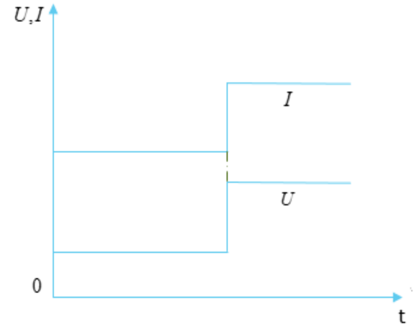
№	Name of energy	Graphs	Formula
1	**Energy saving**		$Min_C = \left[\sum_{i=1}^{N}\sum_{j=1}^{J} P(i;\, j)\bullet t(j)\bullet Ce(i;\, j)\right] +$ $+\left[\sum_{i=1}^{N}\sum_{j=1}^{J} P(i;\, j)\bullet cd(i;\, j)\right]$ Energy saving measures are measures to seasonally reduce energy consumption through efficient energy consumption and reduce losses. $Pnew(i) \le Pold(i)$ $Pnew(i)$ - demand type of load "i" in the interval "j" after the introduction of efficiency. $Pold(i)$ - demand type of load "i" in the interval "j" before the introduction of efficiency.
			$Pnew(i)$ does not allow to increase the value of power, which is the limit and set by the scheduler.
2	**Load constructin**		These measures are aimed at managing the seasonal increase in energy consumption. This is based on the implementation of intelligent systems to achieve maximum energy efficiency. $Max.value = \left[\sum_{i=1}^{N}\sum_{j=1}^{J} P(i;\, j)\bullet t(j)\bullet Ce(i;\, j)\right] +$ $+\left[\sum_{i=1}^{N}\sum_{j=1}^{J} P(i;\, j)\bullet cd(i;\, j)\right]$ $Pnew(i) \ge Pold(i)$ $Ce(i;\, j)$ - the cost of energy consumed "i" by the consumer at the "j" time interval t;

			$cd(i;j)$ - the cost of power consumption "i" by the consumer at the "j" time interval t.
3	**Reduction of peak load**		These are measures or programs that aim to equalize the consumption schedule by directly controlling the load, disconnecting consumer equipment, or introducing dispersed generation $Max.K_z = \left[\left[\sum_{j=1}^{i} P_{TO}(j) \bullet t(j)\right] \backslash \sum_{j=1}^{i} t(j)\right] \backslash .$ $\backslash P_{TO}(K)$ P – this is the limit value set according to the potential. K – this is the time interval in which the total need for all types of loads $P_{TO}(K)$ is the maximum. $P_{TO}(K)$ - maximum demand for all types of loads for all time intervals. $P_{TO}(K) \geq P_{TO}(j), j = 1,...J; j = K$

			limitation $Pnew(i) \geq Pold(i)$ $Pnew(i) \leq P_1$ $Pnew(i) \geq P_2$ $P_2 \leq P_1$
4	**Filling gaps**		These are activities / programs that encourage off-peak consumption. They are aimed at increasing own consumption in areas of general decline in energy consumption. Consumer incentives are provided at much lower rates. $Max.K_z = \left[\left[\sum_{i=1}^{N} \sum_{j=1}^{J} P(i;j) \bullet t(j) \right] \backslash \sum_{j=1}^{J} t(j) \right] \backslash \sum_{j=1}^{N} P(i,K)$ $Max.K_z = \left[\left[\sum_{i=1}^{N} \sum_{j=1}^{J} P_{TO}(j) \bullet t(j) \right] \backslash \sum_{j=1}^{J} t(j) \right] \backslash \sum_{j=1}^{N} P_{TO}(K)$ $Pnew(i,j) = Pold(i,j)$ $Pnew(i,j) \geq Pold(i,j)$
5	**Load transfer**		These are demand management measures that move the load from the period of highest consumption to the period of low consumption without changing the total load. This is possible with the inclusion of the scattered generation. $Max.K =$ $= \left[\left[\sum_{j=1}^{J} P_{TO}(j) \bullet t(j) \right] \backslash \sum_{j=1}^{J} t(j) \right] \backslash \sum_{j=1}^{N} P_{TO}(K)$

			$P_{new(i)} = P_{old(i)}$ $P_{new} \le P_2$
6	**Flexible modeling**		It is a set of actions and integrated planning between generating companies and consumers, taking into account the needs of a specific period of time and time. In the system, on the time interval "T", we can distinguish 4 groups of modes and the relationship between the graphs of the instantaneous values of power generation $P_{G(t)}$ and consumption $P_{Load(t)}$ $P_{G(t)} = P_{Load(t)}, \forall t, t \in [0;T];$ $P_{\Gamma(t)} = P_{H(t)}$ full coordination of generator and load modes (consumer) $P_{G(t)} \ne P_{Load(t)}; \frac{1}{T}\int_0^T P_G(t)dt =$ $= \frac{1}{T}\int_0^T P_{Load}(t)dt;$ $P_{G(t)} = P_{Load(t)}$ - should be provided in the use of technical means: energy storage, reactive power compensation, compensation of non-sinusoidality and asymmetry. $P_{G(t)} \ne P_{Load(t)}; P_G \le P_{Load}$ – should be implemented as for the second group + balance implementation $P_{G(t)} \ne P_{Load(t)}; P_G \ge P_{Load}$ – the level of increase of power consumption on available loading + possibility of connection of additional loading should be provided.

7	**Proportional increase in voltage and current**	 	The proportional increase in voltage and current is written in increments: $\Delta U = \Delta I = \Delta$ value for the square of active power: $P^2 = (U_1I_1\delta + U_1I_1\Delta^2(1-\delta))^2 =$ $= P^2U_1^2I_1^2(\delta+\Delta^2(1-\delta))^2$ $S^2 = U_1^2I_1^2(\delta+\Delta^2(1-\delta))^2$
8	**Consumption at different time intervals**	 	We use the average value of voltage and current: $U_{average} = \dfrac{U_1t_u + U_2(T-t_u)}{T}$ $I_{average} = \dfrac{I_1t_1 + I_2(T-t_u)}{T}$ We use the value of the sum of voltage and current: $\left\{\begin{array}{l} U^2 = U_1^2\delta_u + U_2^2(1-\delta_u) \\ I^2 = I_1^2\delta_1 + I_2^2(1-\delta_1) \\ \delta_u = t_u \backslash T \\ \delta_1 = t_1 \backslash T \end{array}\right\}$ In the case of curved shapes that are symmetrical: $t_u = t_1$ $t_1 = t_2 = t$ $t_1 + t_2 = T$

			$P=\frac{U_1 I_1 t}{Tt}+\frac{(U_1+\Delta U)\bullet(I_1+\Delta I)(Tt-t)}{Tt}$

Example of a technological process in relation to the consumption

Technological processes, in our task, take place in two objects of the power system. Consider the consumption for one object 1. Energy consumption comes from the central network. The system is equipped with RES for each object.

If the consumption is specific to a particular case, we can change the schedule by transferring the load to another time interval:

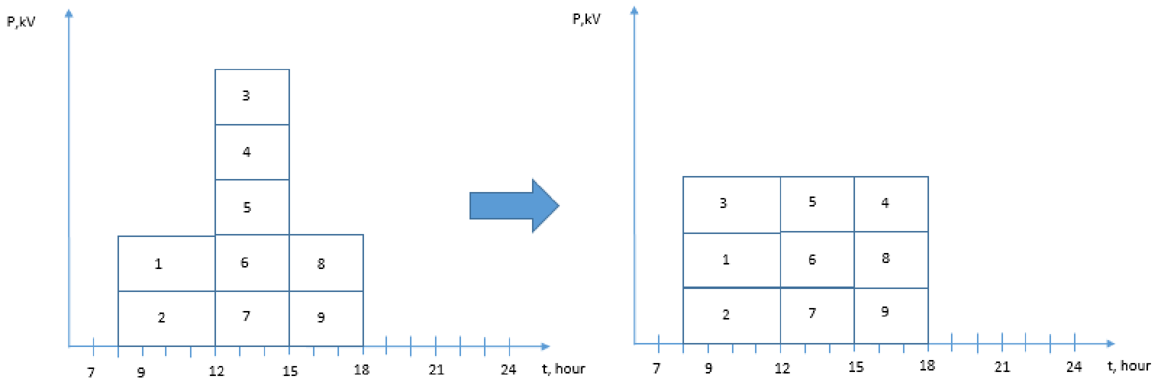


Figure 35. An example of reducing hierarchical consumption at peak times

If you use RES generation, then your own generation allows you to reduce energy consumption from the grid:

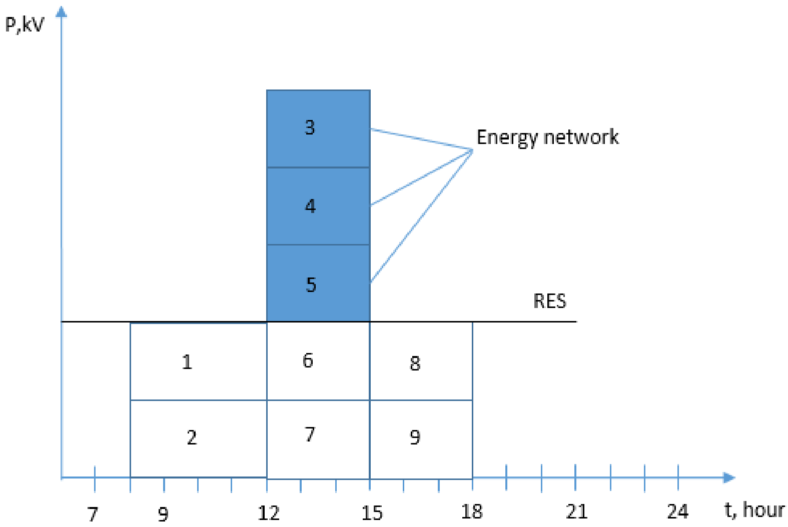


Figure 36. Fission to consumption of RES and consumption from the network.

That is, we have the opportunity, relative to the network, to increase the percentage of own generation and reduce the price of energy from the network.

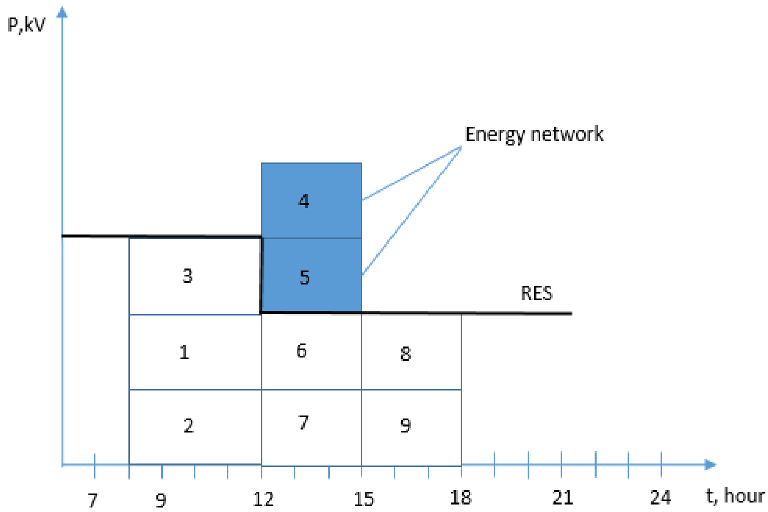


Figure 37. An example of the division of the technological process.

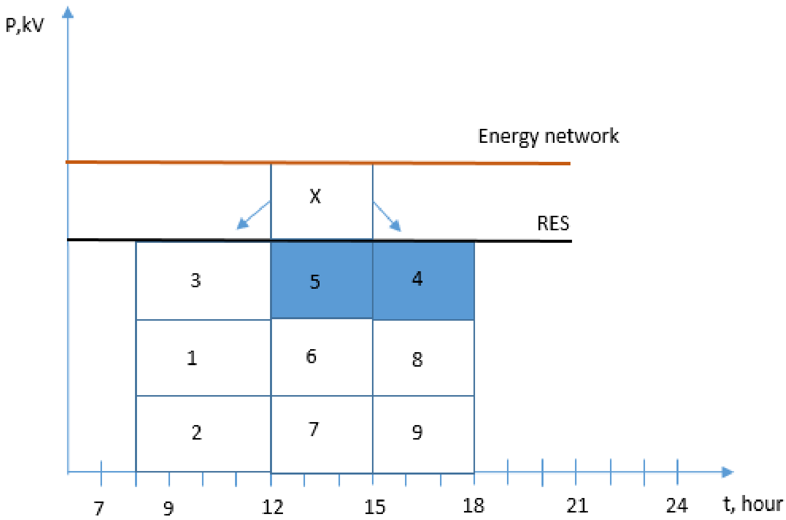


Figure 38. An example of the division of X consumption of the technological process

If you have your own generation, it can reduce failures in energy consumption and reduce the percentage of grid consumption:

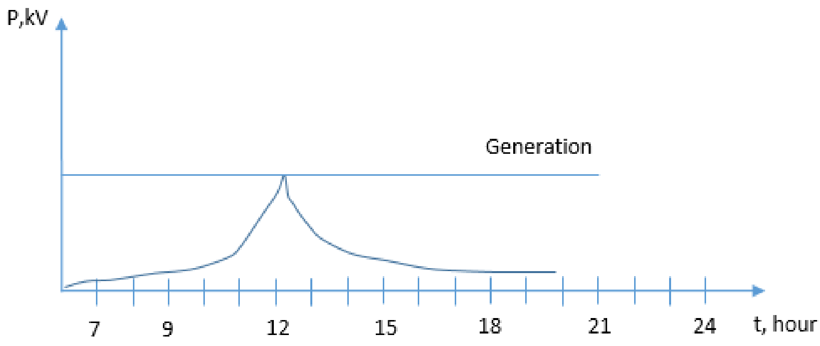


Figure 39. Maximum generation under favorable conditions

This energy can be stored in the battery, or used in combination with network consumption.

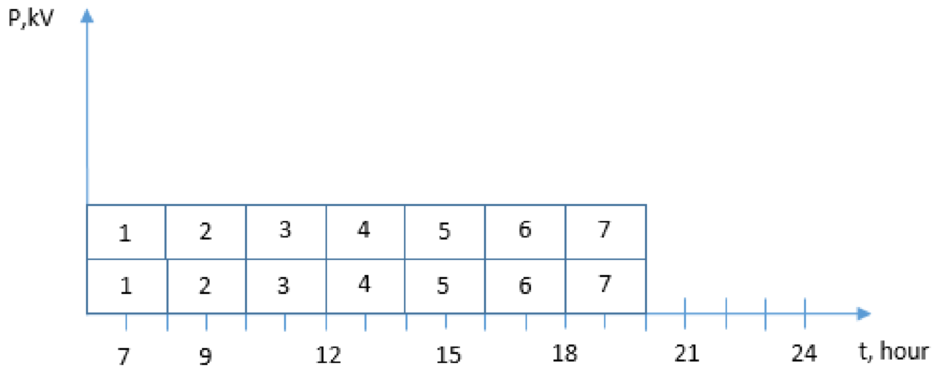


Figure 40. An example of a continuous technological process.

There is a need to fill in the gaps in the schedule of energy consumption, if there is a need to change the load relative to the time characteristics and mode of operation (day, night).

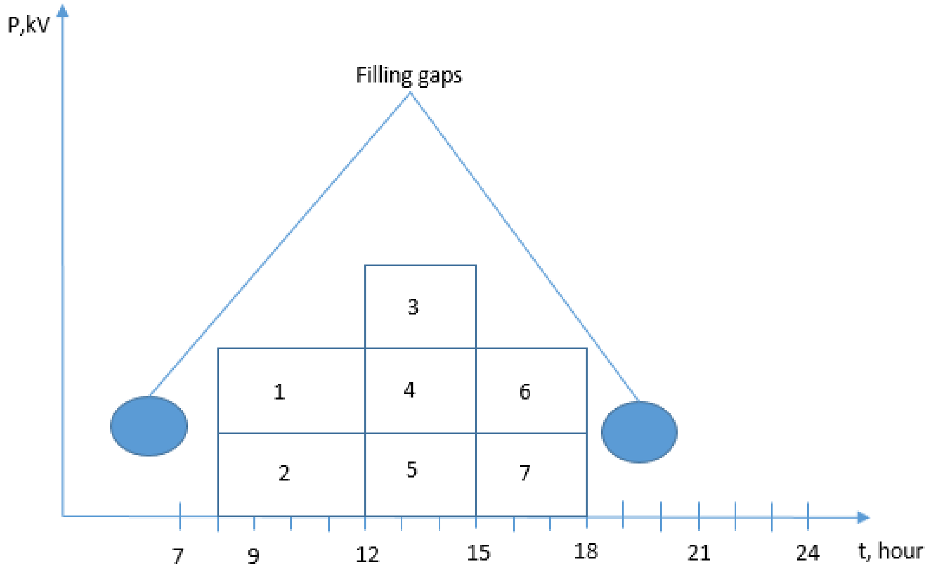


Figure 41. Filling gaps in the technological process.

A combined consumption option is also possible. We can shift consumption to an interval where there is no consumption, so that the technological process is uninterrupted and idle. The technological process must correspond to a constant efficiency of production.

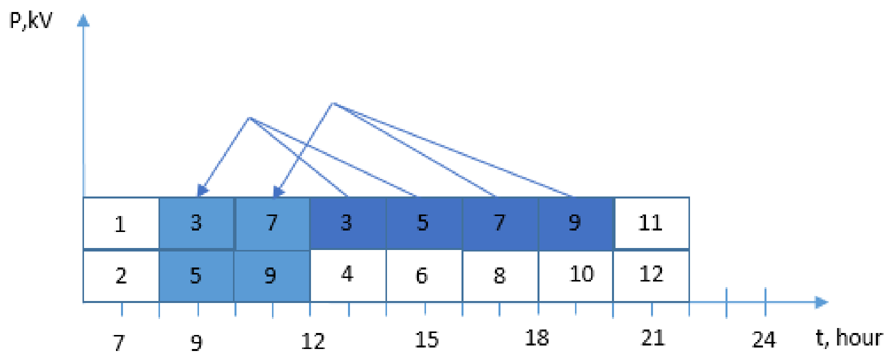


Figure 42. Transfer of technological processes

If the technological process must be in certain time intervals, then:

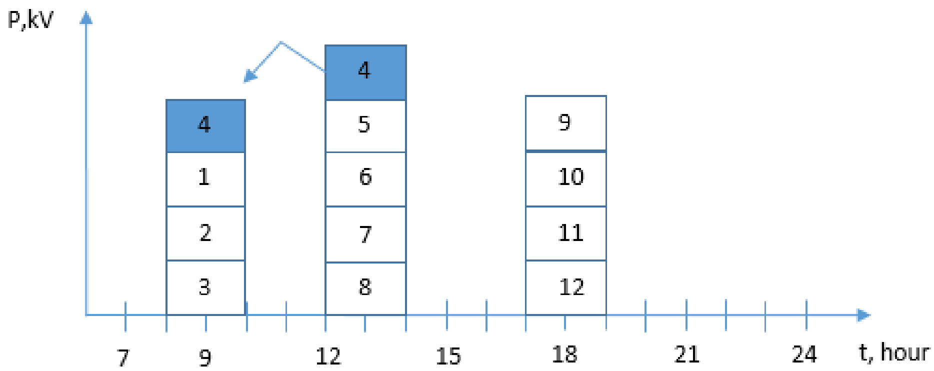


Figure 43. Tansfer from peak time to process technology

1 - We can change the consumption by transferring the partial load to another interval.

2 - Use our RES

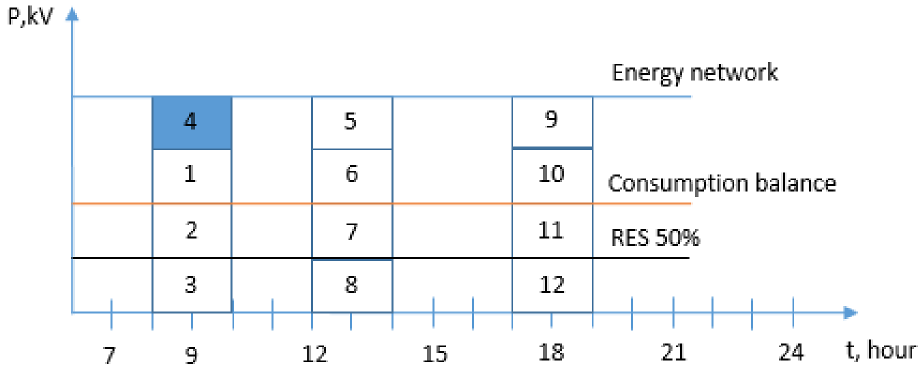


Figure 44. Energy division

In order to balance consumption during "peak times", we can build all loads evenly:

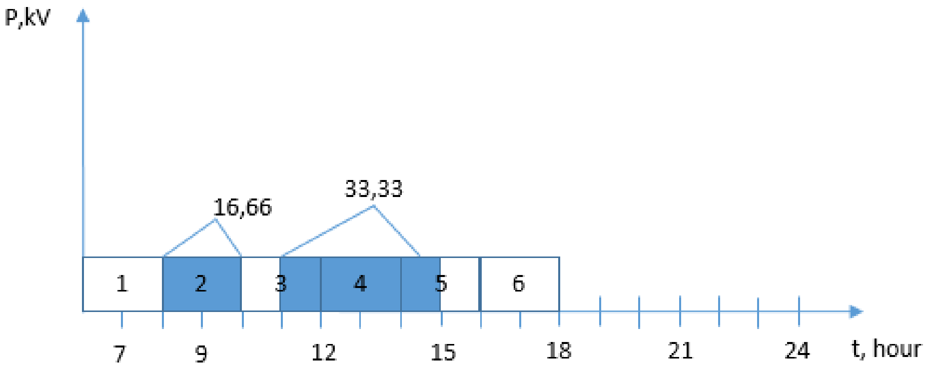


Figure 45. Energy separation by 50% generation

We can use 50% RES during peak times, but online consumption should be mandatory. Moreover, by generating RES energy, we can fill the consumption of 50% or the relative share of energy (15%; 25%; 40%; 50; 60%) relative to the battery.

Example of technological process (object 1)

Consider the example of generation control, consumption, optimization balancing of the system. The system has a battery, generation from RES, consumption from the network. We offer an optimization option: power adjustment in time intervals.

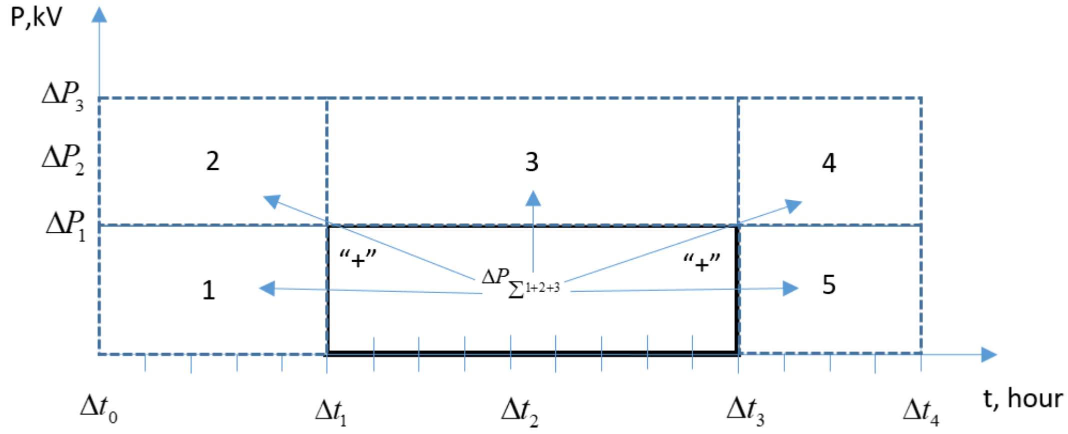


Figure 46. Technological process in time characteristics.

$P_{all.cons.} = \Delta P_{\sum 1+2+3} \cdot (\Delta t_1 + \Delta t_2 + \Delta t_3)$ - power consumption at a given interval.

$P_{all} = \Delta P_{\sum 1+2+3} \cdot (\Delta t_{1+2+3} + \Delta t_0 + \Delta t_4)$ - power consumption throughout the day.

To change $\Delta P_{\sum 1,2,3}$ on a specific interval you need to calculate the values:

1 - $P_{change1} = \Delta P_{\sum 1,2,3} \cdot (\Delta t_0 + \Delta t_1 + \Delta t_2 - \Delta t_3)$

2 - $P_{change2} = \Delta P_{\sum 1,2,3} = (\Delta P_1 + \Delta P_2 + \Delta P_3) \cdot (\Delta t_0 + \Delta t_1)$

3 - $P_{change3} = \Delta P_{\sum 1,2,3} = (\Delta P_1 + \Delta P_2 + \Delta P_3) \cdot (\Delta t_1 + \Delta t_2 + \Delta t_3)$

4 - $P_{change4} = \Delta P_{\sum 1,2,3} = (\Delta P_1 + \Delta P_2 + \Delta P_3) \cdot (\Delta t_3 + \Delta t_4)$

5 - $P_{change5} = \Delta P_{\sum 1,2,3} \cdot (\Delta t_3 + \Delta t_4)$

The possibility of power distribution in different intervals is also considered. You can increase the power or decrease it.

$$\frac{P_{\sum}}{2} = P_{\sum 1} + P_{\sum 2}$$

$$P_{\sum 1} = \Delta P_1 + \Delta P_2 + \Delta P_3 \cdot (\Delta t_1 + \Delta t_2)$$

$$P_{\sum 2} = \Delta P_1 + \Delta P_2 + \Delta P_3 \cdot (\Delta t_2 + \Delta t_3)$$

$$P^{+}_{1+2} = P_{\sum 1} \cdot (\Delta t_0 + \Delta t_1)$$

$$P^{+}_{4+5} = P_{\sum 2} \cdot (\Delta t_3 + \Delta t_4) \qquad (101)$$

$$\Delta P_{\sum 1,2,3} = \Delta P_1$$

$$\Delta P_{1,2,3} = \Delta P_{\sum 1,2,3} + \Delta P_2 + \Delta P_3 \cdot (\Delta t_1 + \Delta t_2 + \Delta t_3) \tag{102}$$

generation from the system

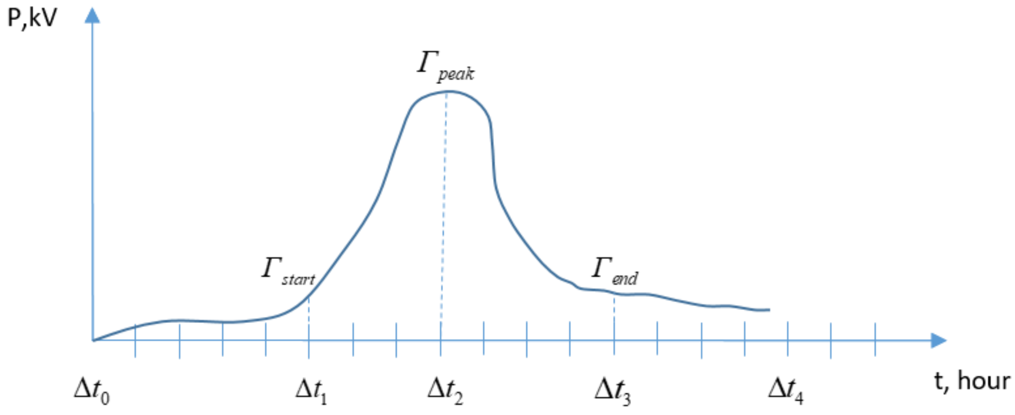


Figure 47. System generation

Peak generation - energy production with the maximum generation factor.

Start generation - the production of initial energy with a constant generation factor

End generation - the completion of energy production, according to geothermal conditions (sun).

Generation can be obtained by storing energy in the battery and use it for your own needs. Peak generation can be reduced by using its own generation from RES.

$$\Delta t_0 + \Delta t_1 \cdot G_{start} \leq G_{peak} \cdot \Delta t_1 + \Delta t_2 + \Delta t_3 \tag{103}$$

$$\Delta t_0 + \Delta t_1 \cdot G_{start} \sim G_{end} \cdot \Delta t_3 + \Delta t_4 \tag{104}$$

RES of the sun

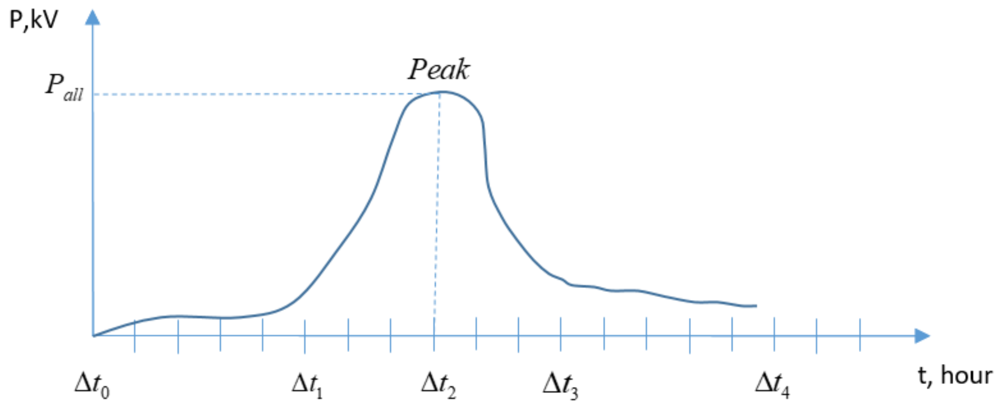


Figure 48. Solar generation system

The sun produces generation only during the day. It can be used for accumulation or consumption for own needs. It is impossible to change the RES of the sun. It is possible to use a combined method of consumption (network + RES), if appropriate in a particular matter.

$$P_{sun}^{gen} = P_{sum} \cdot (\Delta t_0 + \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4) \tag{105}$$

RES of the wind

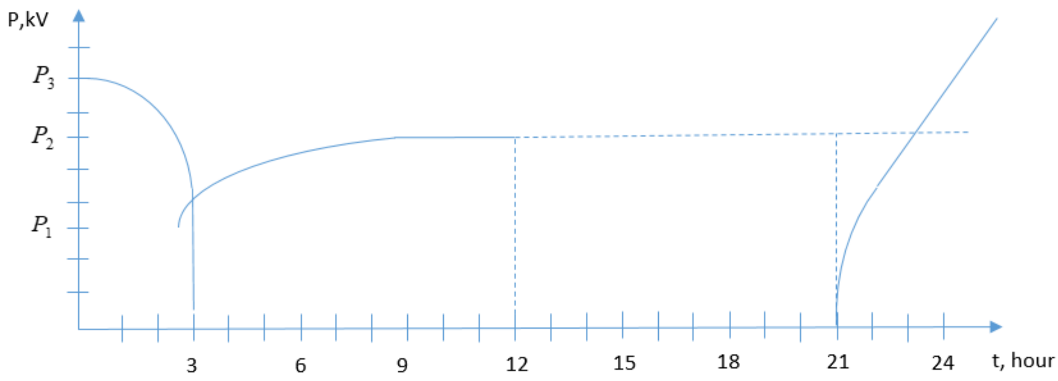


Figure 49. Wind generation system

The wind resistance depends only on the relevant environmental conditions. Accordingly, having indicators of meteorological conditions and phenomena, it is possible to make forecasting of generation. The location of wind turbines is a very technical, important issue.

We observe such an example that on the interval $t_0 - t_3 - t_6$ we have a generation P_3.

From $t_6 - t_9 - t_{12}$ we observe generation P_2. From $t_{12} - t_{15} - t_{18} - t_{21}$ - we have a generation failure P_0. Generation $t_{21} - t_{24}$ - gradually increases, and there is power $t_{21} - t_{24} \cdot P_1 + P_2 + P_3$.

Using the battery

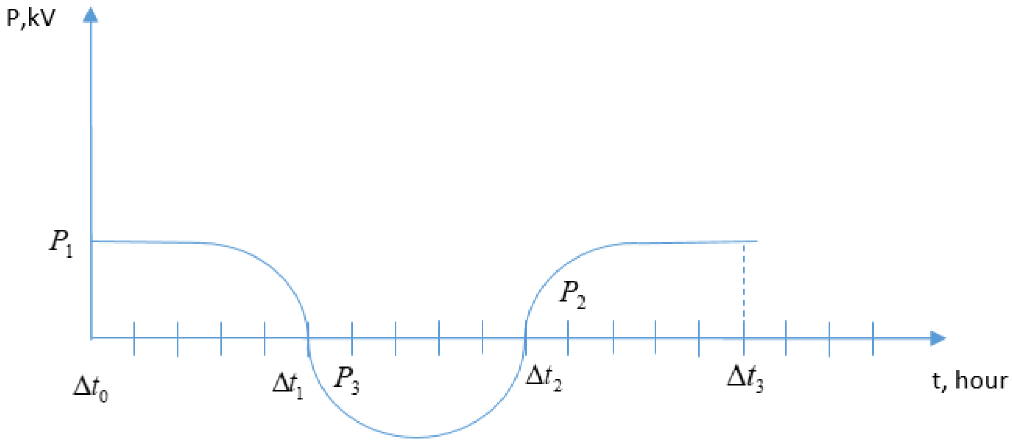


Figure 50. Battery usage during peak times

Batteries are used for their own needs. If at intervals $\Delta t_0 - \Delta t_1$ та $\Delta t_2 - \Delta t_3$ there is an accumulation of charge, then on $\Delta t_1 - \Delta t_2$ is its category (consumption) for the technological process.

$$P_{sum} = (P_1(\Delta t_0 + \Delta t_1)) + (P_2(\Delta t_2 + \Delta t_3)) - (P_3(\Delta t_1 + \Delta t_2)). \quad (106)$$

Also, all intervals can be positive if there is a charge and negative if there is consumption (P3).

Transfer of consumption

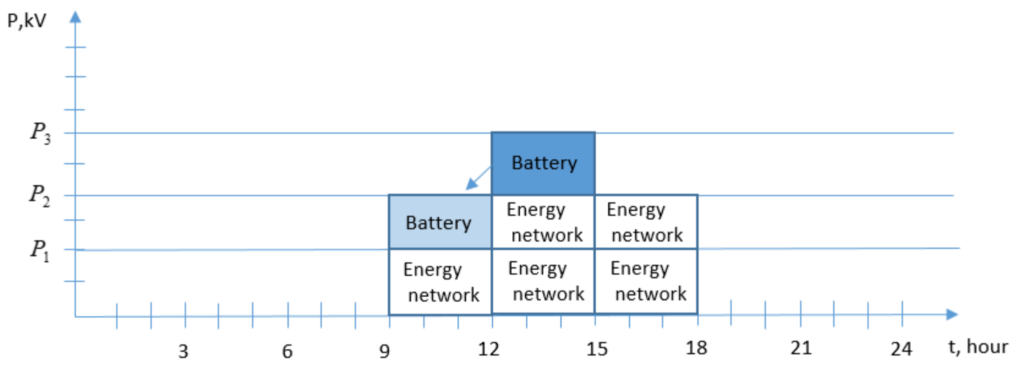


Figure 51. Transfer process

Can be included in battery consumption. All other intervals are network consumption. You can transfer the load of the "battery" in the interval $t_9 - t_{12}$, thus we are able to reduce the peak load.

We can use our own generation of RES sun + wind.

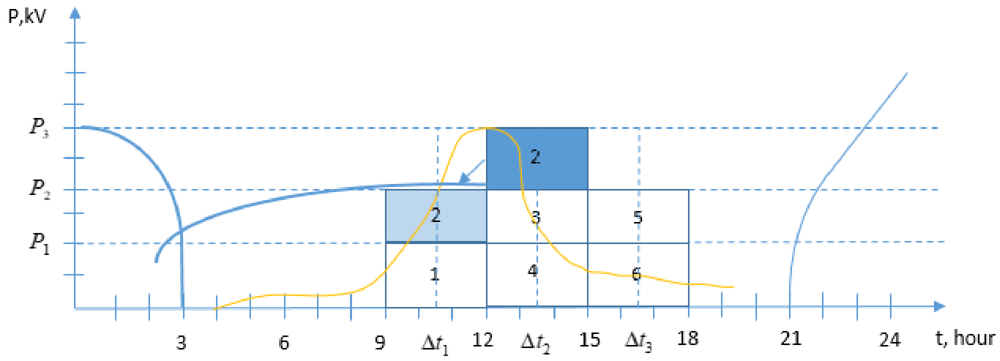


Figure 52. Use of wind and solar generation for consumption.

Block 2 can be transferred to the zone of generation of RES sun + wind. Blocks 3 and 5 can be offset Δt_1 and Δt_2 when changing block 2 by an interval $t = 6 - 9$ where the generation of RES covers consumption. In this example, wind and sun can partially cover consumption.

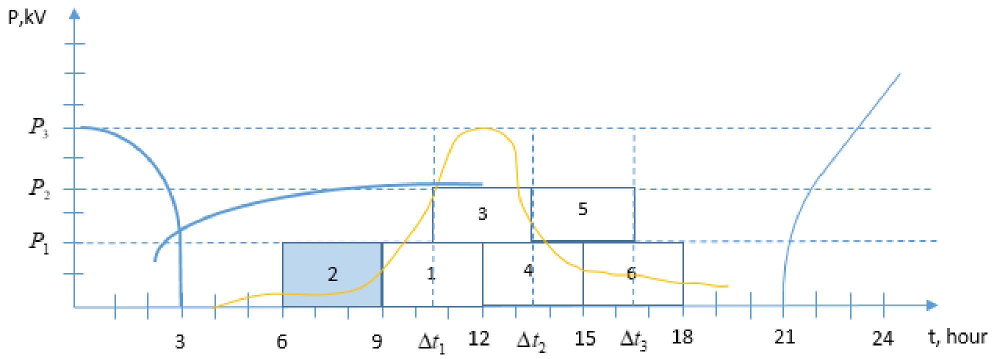


Figure 53. Use of wind and solar generation for consumption.

RES of the sun, when moving blocks 3 and 5 - to the interval $\Delta t_9 - \Delta t_1 - \Delta t_{12} - \Delta t_{15}$ - is able to completely cover the peak from our battery - generation.

Power increase, or change of time characteristic

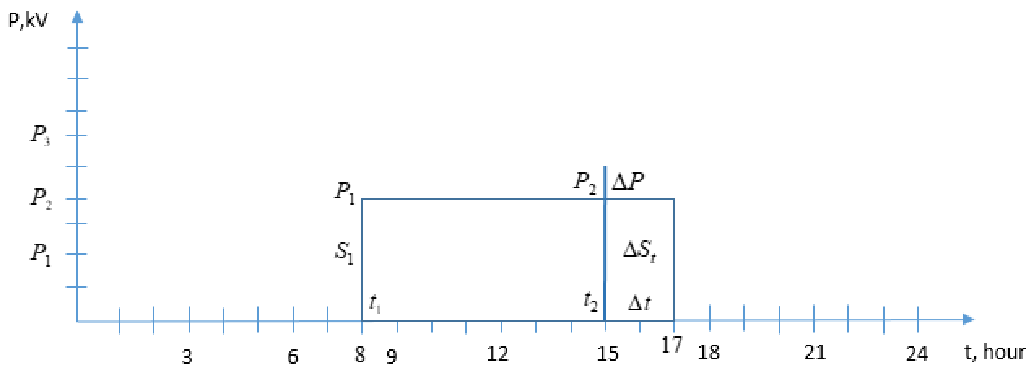


Figure 54. Increase power or change the time characteristic in the system

$$S_1 = P_1 \cdot t_1 + P_2 \cdot t_2$$

$$\Delta S = \Delta P \cdot \Delta t + S_1 \tag{107}$$

The process allows you to add power and shift by a certain interval.

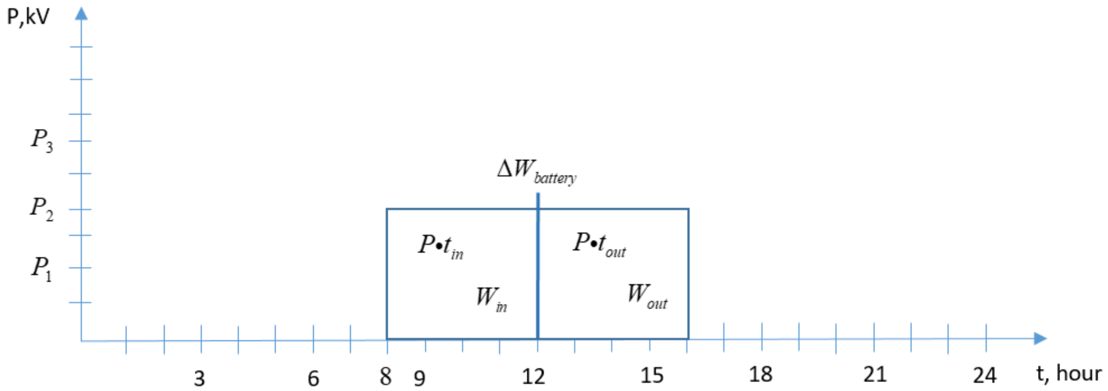


Figure 55. An example of the process of charging and discharging the battery.

Assume that the battery is discharged by 50%, then the battery has a constant, constant capacity, it can be increased by adding capacity (battery). The battery has the ability to discharge and charge. To self-discharge, due to the influence of certain factors: chemical and external.

$$\Delta t_{battery} = P \cdot t_{in} - P \cdot t_{out} \cdot \Delta t = 50\% BATTERY \tag{108}$$

Δt - the time of transition of the battery to a state of charge or discharge.

$$\Delta W_{battery} = W_{in} \tag{109}$$

The main characteristics of the battery are:

1 – Electromotive force «E»

2 – Internal resistance «r_i»

3 – Maximum power «$P_{\max}$»

4 – Maximum current «$I_{\max}$»

In practice, an important feature of batteries is that their EMF can be stable for a long time. The current source accumulates full power $P = I \cdot E$. Useful power consumed in the external circuit:

$$P_k = I \cdot U = I^2 R = I(E - Ir_i) \tag{110}$$

Efficiency of the battery

$$\eta = P_k / P = I(E - I \cdot r_i) / I \cdot E = (E - Ir_i) / E = U / E \qquad (111)$$

$$\eta = I^2 R / I^2 (R + r_i) = R / (R + r_i) \qquad (112)$$

The power and efficiency of the battery depends largely on the load, ie on the current I passing in this circuit. Graph $P_k = f(I)$ is expressed by a segment of a parabola whose axis is parallel to the y-axis, so there is an extreme point M on the curve $P_k = f(I)$, whose ordinates can be determined from the formula:

$$I_M = E / (2r_i); \; P_{KM} = EI_m / 2 \qquad (113)$$

From these formulas it follows that the source will give the maximum power when the external resistance is equal to the internal: $R = r_i$. In this case, as can be seen from the formula $\eta = I^2 R / I^2 (R + r_i) = R / (R + r_i)$, the efficiency is 50%, in addition, the efficiency is 1 when the resistance is 0.

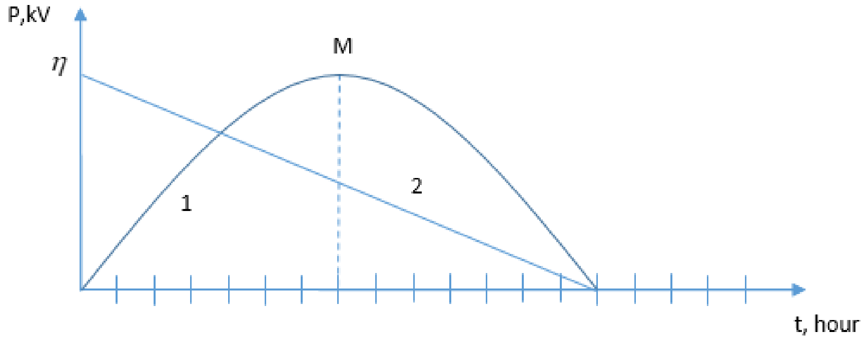


Figure 56. An example of the time division of consumption in relation to efficiency

Characteristics of the battery:

1. Capacity: E(A*hour) = I [A] x T [hour]; I – direct current of the battery discharge; T - discharge time.

2. Dependence of energy and battery capacity: [Dj] = I [A] x U [V] x T [s];

The higher the voltage in the battery, the more energy can be stored. It characterizes the magnitude of the voltage and the time of its flow. It follows that the energy of the battery is equal to the product of capacitance and rated voltage.

W [Watt*hour] = E [A*hour] x U [V]; E – battery capacity. U - battery voltage.

3. Battery energy and its capacity

Battery energy is equal to the product of the energy of one battery by their number

Battery charge and capacity

Characteristic of the battery, which demonstrates the ability of the battery to discharge under constant load for a certain period of time (15 minutes).

E [A*hour] = W [Watt]/4

The discharge and charge times are power-dependent. For these purposes, use a special formula that was developed by Peckert: $I_p \cdot T = const$

Where, p – is a Peckert number and is an indicator of degree. If lead-acid batteries, the number of p = 1,15-1,35.

Only a few calculations allow us to obtain a formula that characterizes the capacity of the battery E at the current of the discharge I:

$$E = E_n \cdot (I_n / I)_{p-1} \quad (113.1)$$

With E_n is the nominal capacity of the battery, and the indicator I_n - this is the discharge current, which depends on the specified nominal capacity.

Sun generation

Global formula for estimating the electricity produced at the output of the photovoltaic system: $E = A \cdot r \cdot H \cdot PR$

E – energy (kV\hour)

A – total area of the solar panel (m^2)

r – energy output of the solar panel (%)

H – average annual solar radiation on inclined panels (shading not included)

PR – productivity ratio, loss ratio (range from 0.5 to 0.9)

PR – depends on the location, technology and size of the system:

inverter loss (4-10%)

temperature loss (5-18%)

losses of direct current cables (1-3%)

shading (0-80%)

losses with weak generation (3-7%)

dust and other (2%)

Mathematical model photovoltaic battery

Photovoltaic battery capacity (PBC), under standard conditions $I_{sys} = 1kV / m^2; t = 25^o_C$ is called rated power.

The output power of the PBC at a different flux density of solar radiation $I_{\beta(t)}$ will be proportional to: $P_{PBC(t)} = P_{PBC_{const}} \dfrac{I_\beta}{I_{RES}}$

Where, $P_{PBC(t)}$ - output power PBC.

P_{PBC} - rated power of PBC under standard conditions.

K_z - the coefficient of reduction of the efficiency of PBC

I_β - the average value of the flux density of solar radiation that reaches the surface of the PBC over time.

I_{RES} - the flux density of solar radiation that reaches the surface of the PBC.

Power consumption in the elements of the PBC is taken into account by the coefficient of reduction of the efficiency of the PBC K_z

$$P_{PBC(t)} = P_{PBC_{const}} \bullet K_z \bullet \frac{I_{\beta(t)}}{I_{RES}} \tag{114}$$

This does not take into account the effect of ambient temperature on the output power of the PBC.

Mathematical model of wind power plants

The power delivered by the wind turbine (WPP) to the grid depends on the wind speed, the height at which the generator is installed and the output characteristics of the generator. The speed of air near the earth's surface depends on the height, and the power given by the wind turbine depends on the cube of the speed of air masses. The height of the mast significantly affects the output power. Most often, to calculate the air velocity, from the height of the anemometer to a given height using the following laws: a) logarithmic

$$u_h = U_a \frac{\ln \frac{h}{Z_o}}{\ln \frac{h_a}{Z_o}}; \tag{115}$$

u_h - air velocity at a height of h

U_a - air speed at the height of the anemometer h_a

Z_o - tabular parameter of unevenness of the earth's surface.

b) potential

$$u_h = u_a \left(\frac{h}{h_a}\right)^\tau \tag{116}$$

τ - an indicator of the degree that depends on the unevenness of the earth's surface.

Mathematical model of the battery

Equation of battery dynamics in finite increments:

$$g_{battery}(t+\Delta t)=g_{battery}(t)(1-\sigma\Delta t)+[P_{in}(t)\eta_{in}-P_{out}(t)\eta_{out}]\Delta t \qquad (117)$$

Where, $g_{battery}$ - battery charge, σ - self-discharge coefficient, $P_{in}(t)$ та $P_{out}(t)$ - charge and discharge power, respectively, η_{in} та η_{out} - efficiency of charge and discharge, respectively, Δt - time interval

We accept: $\eta_{in}=\eta_{out}=\eta_{s}$;

Enter the notation: $P_{\Delta(t)}=P_{in(t)}-P_{out(t)}$

We get: $g_{battery}(t+\Delta t)=g_{battery}(t)(1-\sigma\Delta t)+\Delta P(t)\eta_{S}\Delta t$

Value $\Delta P(t)$ will be positive in case of charge and negative in case of discharge.

After performing the limit transition and calculation for this formula, we obtain the equation in differential form:

$$\frac{d}{dt}=g_{battery(t)}=-g_{battery(t)\sigma}+P\Delta(t)\eta_{S} \qquad (118)$$

Applying the Laplace transform, we obtain the equation of battery dynamics in operator form: $Sg_{battery}=-g_{battery(S)\sigma}+P_{\Delta(s)\eta_{S}}$

Hence the transfer function of the battery:

$$W_{battery(S)}=\frac{P_{\Delta(S)}}{g_{battery(S)}}=\frac{\eta_{S}}{S+\sigma} \qquad (119)$$

As the battery has an initial charge g_{0}, and the mode of operation is subject to a restriction on the charge level (the limit on the discharge current is neglected), then: $g_{battery_{\min}}\leq g_{battery_{(t)}}\leq g_{battery_{\max}}$

Where, $g_{battery_{\min}}$ - the minimum battery level that is standardized by the manufacturer. $g_{battery_{\max}}$ - maximum charge level.

Operation and management of RES + battery

Power entering or leaving the battery is determined by the difference between the power of energy sources (PBC and wind turbine) and power consumption:

$$\Delta P(t)=[P_{SPP(t)}+P_{WPP(t)}]-P_{consum(t)} \qquad (120)$$

Where, $P_{SPP(t)}, P_{WPP(t)}$ - power of sun plants and wind turbines. $P_{consum(t)}$ - current power consumption.

Since the degree of battery charge is limited, the receiving / transmitting power of the battery will be determined by the following step:

$$P_{battery(t)} \begin{cases} \Delta P(t), if: g_{battery_{\min}} - g_{battery} \le \Delta P(t)\Delta t \le g_{battery_{\max}} - g_{battery(t)} \\ \frac{1}{\Delta t}[g_{battery_{\max}} - g_{battery(t)}], if: \Delta P(t)\Delta t \ge g_{battery_{\max}} - g_{battery(t)} \\ \frac{1}{\Delta t}[g_{battery_{\min}} - g_{battery(t)}], if: \Delta P(t)\Delta t \ge g_{battery_{\min}} - g_{battery(t)} \end{cases} \quad (121)$$

Excess energy flow that cannot be accumulated in the battery:

$$g_{battery(t)} = g_{battery_{\max}}$$
$$P_x(t) = \Delta P(t) - P_{battery}(t) \quad (122)$$

Power shortage, which can not compensate for the battery:

$$g_{battery(t)} = g_{battery_{\min}}$$
$$P_m(t) = \Delta P(t) - P_{battery}(t) \quad (123)$$

So, $P_m(t)$ - will be the power provided by the RES.

Assessment of the optimal construction and operation of SES requires the development of adequate criteria. The traditional approach to assessing the correctness of the configuration of SES capacities is to ensure the balance reliability or adequacy of the electricity generation system. In general, power balance and energy balance can be considered, although these physical quantities are related. Demand indicators also come to the fore. However, when assessing the economic performance of SES, it is also necessary to take into account the rational use of energy produced. As a result, there is a problem of refining the components of the optimization problem taking into account the power of Frieze.

Features of the formation of the optimization problem depends on the role and functions of loads, in particular, the requirements for the schedules of electricity generation and power consumption (operating modes), their energy and economic characteristics and indicators as elements of optimization. There is a problem of forming an optimization problem provided:

- own consumption;
- cooperative consumption;
- sale of electricity to the centralized system through an aggregator.

When formulating the optimization problem, it should be borne in mind that in most cases economic and technical components are used as criteria, and social and environmental constraints (for example, environmental acceptability or demand) are used as constraints.

We will formulate possible variants of the balance of instantaneous powers in the system with the allocation of instantaneous powers of the $p_{SPP}(t)$, the battery $p_{battery}(t)$, he centralized network $p_{Line}(t)$ and the actual loads of the consumer $p_{Load}(t)$.

1) $p_{SPP}(t) + p_{Line}(t) + p_{battery}(t) = p_{Load}(t)$;

2) $p_{SPP}(t) + p_{Line}(t) – p_{battery}(t) = p_{Load}(t)$;

3) $p_{SPP}(t) – p_{Line}(t) + p_{battery}(t) = p_{Load}(t)$;

4) $p_{SPP}(t) – p_{Line}(t) – p_{battery}(t) = p_{Load}(t)$.

From the ratios for options 1) - 4) in the future can be obtained power balances when selecting power from one generator (network or AB), as well as when working with a group of two generators (network and AB). As a result, we get the following seven options for the balance of instantaneous power:

5) $p_{SPP}(t) = p_{Load}(t)$;

6) $p_{Line}(t) = p_{Load}(t)$;

7) $p_{battery}(t) = p_{Load}(t)$;

8) $p_{SPP}(t) + p_{Line}(t) = p_{Load}(t)$;

9) $p_{SPP}(t) – p_{battery}(t) = p_{Load}(t)$;

10) $p_{SPP}(t) + p_{battery}(t) = p_{Load}(t)$;

11) $p_{SPP}(t) – p_{Line}(t) = p_{Load}(t)$.

The real daily schedule of SPP ventilation consists of combinations of the given variants.

On the basis of the given relations it is possible to formulate, in particular, the following optimization problems:

- maximum generation to the network (from SPP);
- minimum network consumption (without SPP generation);
- maximum own consumption (SPP generation);
- minimization of funds for electricity payment (without SPP or with SPP);
- maximization of funds for own generation taking into account their needs.

As an example, we give the target functions for assessing the suboptimal processes:

$$W_1 = W_B - (W_{G,R1} + W_{S1}) \rightarrow \min;$$

$$W_2 = (W_{G,R2} + W_{S2}) - W_B \rightarrow \max;$$

$$C_{payment} = C_B - (CG_{,R1} + C_{S1}) \rightarrow \min;$$

$$C_{income} = (C_{G,R2} + C_{S2}) - C_B \rightarrow \max; \qquad (124)$$

In general, a simplified mathematical model for optimization can be expressed in the following equation:

$$\Sigma\, N_{spp} \cdot P_{spp} + \Sigma\, N\text{s} \cdot P\text{s} + N_{line} \cdot P_{line} = W_s + W_{wpp} \qquad (125)$$

Where, N – the number of units of generating or accumulating equipment of the same capacity; P – power that can be issued by a unit of equipment at a particular time; W_s – power consumption by facilities at a specific time; W_{wpp} – network losses; $_{SPP}$ – parameters related to solar power plants; s - parameters related to energy storage systems;

Conclusion for 3 question

This section examines the analysis of the features of the functioning of local power supply systems with flexible generation and active consumers requires a lot of time and resources. The introduction of its own generation at the technological facility allows to reduce the price from the network, which is a positive factor.

The technical system with two objects which have own consumption from a network and own generation is presented. Management system for this object. Accumulative batteries.

Generation has a positive effect on the energy system, if this system is most effectively protected in terms of energy consumption from the grid. The balance and optimization of electricity consumption for a separate technological object are considered and 3 types of energy consumption are presented.

The consumption schedule is designed depending on the technical indicators, namely: capacity, time and price. Designing a schedule of energy consumption should be designed for each power system separately, depending on the typical environmental conditions.

Examples of consumption in relation to a power system with its own generation were presented. Illustrations are made by hand for survey forecasting of the object. Our formulas for specific pricing and energy of power, which depends on time, are given.

Constant formulas for electricity and energy resources, as well as for generation of consumption are given. Mathematical possibilities of renewable energy sources (RES) based in the power system are presented.

The optimal transfer of consumption from the peak interval to a more reliable one, which is a positive factor, is given.

4. DEVELOPMENT OF STARTUP MODEL

4.1 Description of the startup project.

The idea of the project is to create a structural scheme of stabilization and conversion of primary and secondary energy in energy saving systems for devices operating in the field of heavy operation at facilities with severe conditions. On objects where indicators change sharply depending on load schedules according to various structures of system of electric loading. Ability to clearly and extremely control power relative to solar panels that have energy and time characteristics.

The use of this technical means by consumers provides the possibility of optimal control of the technological process and the implementation of optimization actions in relation to the power system.

Innovative equipment must provide the following main characteristics:

• Stabilization and conversion of output energy with control automation in power supply systems.

• analysis and observation of the share of generation of renewable energy sources in the structure of the energy system.

• calculation and obtaining of predicted values, which ensures the use of power balance and increase of the maximum predicted value of RES.

• calculation of the predicted values of the installed capacity of SES and WPP, which ensures the use of all generation capacity.

• monitoring and quality control of SES, WES, RES, and the system as a whole in the presence of modern Internet access systems.

Description of the idea of a startup project, showing the essence and idea of the content of the idea and possible basic criteria, listed in table .

The presented images are placed after table 9.

Table 9. Description of the idea of a startup project.

The content of the idea	Areas of application	Benefits for the user
Development of a structural scheme of stabilization and conversion of primary and secondary energy,	1. Analysis and observation of the share of generation of renewable energy sources in the structure of the energy system.	Ability to monitor and manage the balance of power generation. Existence of clear control in the conditions of the

which is combined with an energy saving system in severe operating conditions	2. Calculation and obtaining of predicted values, which ensures the use of power balance and increase of the maximum predicted value of RES.	increased danger of environment with a possibility of timely reaction of the equipment to situations which are not characteristic of optimum, normal modes. Stability, resistance to harsh conditions and continuity. Rational operation of the system in relation to energy efficiency.
	3. Calculation of the predicted values of the installed capacity of SES and WPP, which ensures the use of all generation capacity.	
	4. Monitoring and quality control of SPP, WPP, RES, and the system as a whole.	
	5. Stabilization and conversion of output energy with control automation in power supply systems.	

Image about the startup project

Where, SPP – Solar power plant; CR - control and regulation equipments; Battery - rechargeable batteries; Electric load – load of energy line. Voltage regulators - is a device that allows you to change the value of the electrical voltage at the output when acting on the controls, or when a control signal is received.

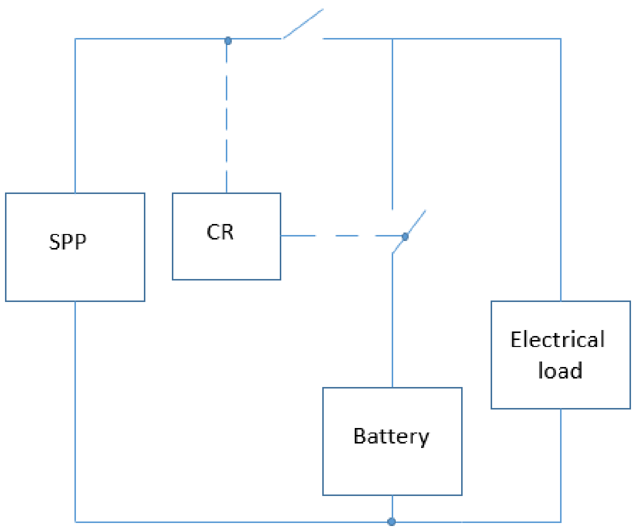


Figure 57. Block diagram of the solar system with power busbar.

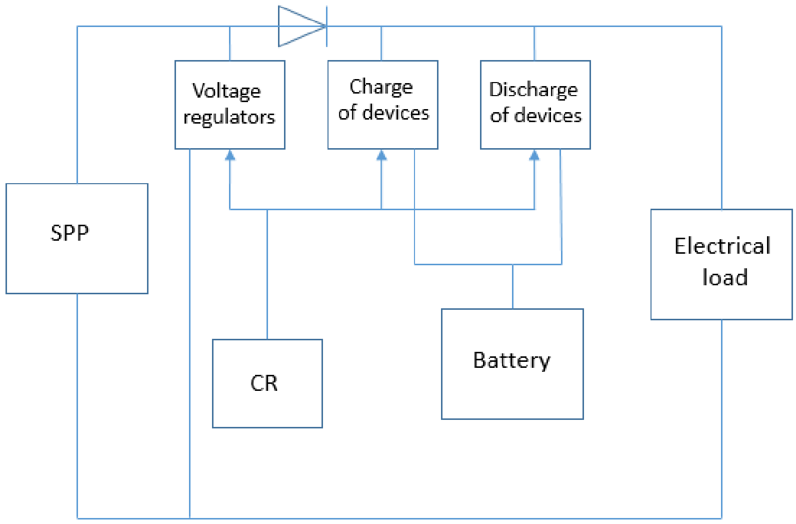


Figure 58. Block diagram with parallel power with power busbar.

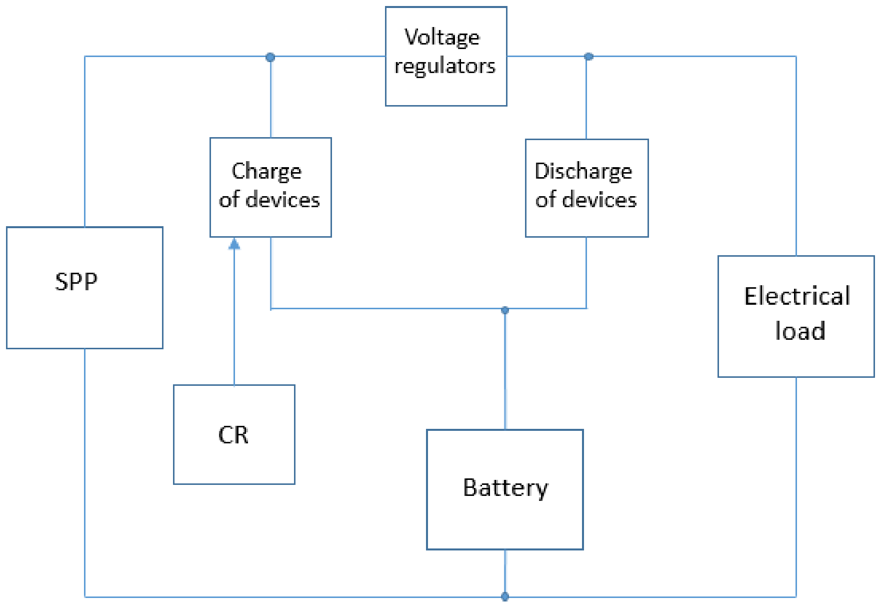


Figure 59. Block diagram with parallel-series power busbar.

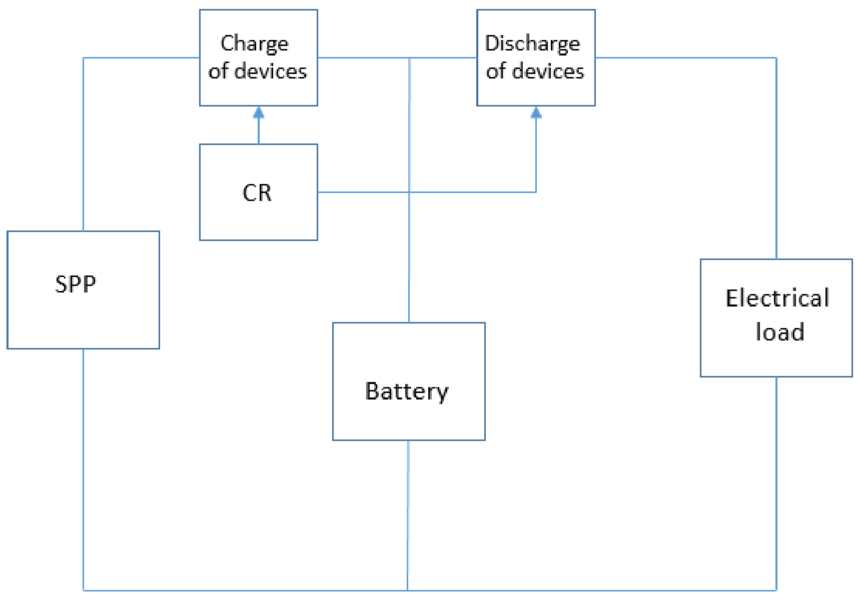


Figure 60. Block diagram with serial connection of charging and discharging of the system.

Voltage stabilizer - an electromechanical or electrical device having a voltage input and output, designed to maintain the output voltage within narrow limits, with a significant change in the input voltage and output load current.

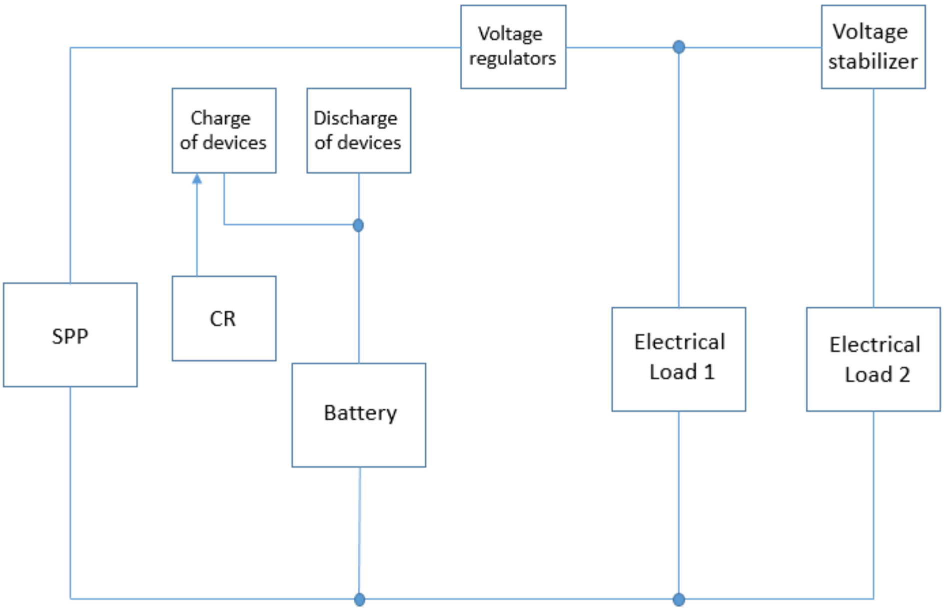


Figure 61. Block diagram with serial connection of charging and discharging of the system to the busbar of the voltage stabilizer.

A certain list of strong and neutral characteristics, as well as properties gives a clear idea of the formation of competitiveness.

Currently, the growing share of renewable energy production has a percentage impact on the energy balance, so it is advisable to use such modernized, modern stabilization schemes. Innovative equipment is upgraded daily to ensure reliable efficiency. As for competition, there is no competition for this equipment.

4.2 Technological audit of the project idea.

Table 10. Technological audit.

№	Project idea	Technologies of implementation	Availability of technology	Availability of technologies
1	Development of voltage stabilization and conversion scheme.	Production of components at the enterprise. Capital optimization at the enterprise for further development of the structural scheme.	Separate components are available, but they need to be upgraded and developed separately for each technological object, or the consumer separately.	This technology is not available for the author. The project requires a lot of capital to create these components and technologies.

The technology is based on the creation of individual elements and the modernization of these elements.

To ensure the creation of efficient production, it is necessary to implement the project and attract investors. Further actions will lead to the development of modern schemes for stabilizing the system. The author of the project can collaborate with other researchers in this area of the project to implement effective modernization in the enterprise.

4.3 Analysis of market opportunities to start a startup project

Analysis of the market environment: compiling a table of factors that contribute to the market implementation of the project and the factors that hinder it, these factors are listed in tables 4.3 and 4.4, respectively. The factors in the table are presented in descending order of importance.

Table 11. Threat factors.

Factor	The content of the threat	The reaction of the company
Sophisticated technical approach in modernization	Lack of investors to implement the software product	Reducing the price of equipment
Difficult political and economic situation in the country	Lack of investors to implement the software product	Reducing the price of equipment
Competition	Creating a similar product	Reducing the price of equipment

Table 12. Opportunity factors.

Factor	Content of the opportunity	The reaction of the company
Creating a system	Creation and modernization, expansion of system capabilities	Product advertising

Table 13. Analysis of competition in the industry by M. Porter.

Components of the analysis	Direct competitors	Potential competitors	Suppliers	Customers	Substitutes
System	Competitors who produce structural, modernized schemes	Price barrier. A time barrier that will not satisfy investors	Factors of optimal consumption of raw materials for the creation of equipment	Interest in adjusting consumer values	The factor of cheap analogues

Based on the results of the analysis of the table, it can be concluded that the market always needs modernized devices and systems that must meet modern needs.

Therefore, as an example, we are developing a system of devices that can meet the needs of markets. Competitiveness is determined by the efficiency factor and price characteristics.

The project is to compile a SWOT-analysis - a matrix of analysis of strong (Power) and weak weights, problems and opportunities, SWOT analysis is shown in table 4.5.

The list of market threats and market opportunities is based on the analysis of threats and factors of the marketing environment. Market threats and market opportunities are the consequences (projected results) of the influence of factors, and, in contrast, are not yet realized in the market and have a certain probability of implementation.

For example: the decline in income of potential consumers - a threat factor, on the basis of which you can make a forecast to increase the importance of the price factor in choosing a product and, accordingly, - price competition (and this is - a market threat).

Table 14. SWOT analysis of a startup project.

Strengths: The startup project is a monopolist in the Ukrainian market. Constant modernization to the current state of systems. Informing, monitoring, adjusting, controlling parameters and quality.	Weak sides: Competition. Requires staff training. Requires quality control. Requires certain documentation.
Features: Modernization and development of the idea.	Threats: Difficult economic and political situation The complex market competition for the modernization plan.

4.4 Development of market strategy of the project.

The first step in developing a market strategy involves defining a market coverage strategy: a description of the target groups of potential consumers. The choice of target groups of potential consumers is made in table 4.6.

Table 15. Selection of target groups of potential consumers.

Description of potential customers	Willingness to consume the product	Oriented demand	Intensity of competition	Simplicity entering the segment
Investors	Full readiness	high	strong	heavily
Government agencies and other enterprises	Повна готовність	high	strong	heavily

We choose a strategy of concentrated marketing.

The definition of the key advantages of the potential product concept is shown in Table 4.7.

Table 16. Identify the key benefits of the concept of a potential product.

Need	The benefits offered by the product	Key benefits
Reliability and quality	Individual access for each client	Individual connection access
Stabilization of values	Quality and completeness	Reliability
Modernization	Further development of modernization	Ability to improve the system

Conclusion for 4 question

In creating a system that has the ability to qualitatively stabilize and convert energy components will be directed to the use of large companies that need it.

Analysis of market opportunities to launch a startup project showed that this project is vulnerable to the following threats: weak purchasing power of the company, increased competition in the market. These threats can be reduced by introducing innovative modernized developments.

The study showed that the greatest demand among all target groups will be state-owned enterprises and companies that need high-quality modern equipment and have problems with the stabilization of basic values.

The review showed that the barrier of a startup project is competition in the equipment market. The analysis confirmed the strengths and weaknesses of this target project, the opportunities inherent in the development of modernized ideas. Threats are real for the political and economic situation in the country.

CONCLUSION OF MASTER'S DISSERTATION

The development of modern energy is quite significant today. The introduction of artificial intelligence in the modern generation of energy is an extremely necessary, technical solution. Artificial intelligence should increase energy efficiency in all areas of energy.

Simultaneous introduction of artificial intelligence and generation should solve the problem of power balance of the power grid. Energy companies must increase their own generation. This will have the opportunity to reduce emissions of toxic substances and carbon dioxide in accordance with the energy concept for emissions by 2035.

Artificial intelligence must be based on a modern system. This system is called a "neural network". The development of the neural network will increase the modernization of all energy systems as a whole. The neural network is modernized very quickly due to the powerful processing of mathematical arrays, which neurons study in the methodology of their training.

Forecasting today has an important impact on the power system. Forecasting for the day ahead is a very important issue. The neural network has the best efficiency in predicting energy consumption with minimal error depending on all other outdated methods.

Methods of optimal resource consumption were presented, thanks to which, enterprises can implement effective target optimal consumption and improve economic indicators. The savings also depend on the correct and clear choice of system optimization.

Optimal consumption depends on factors such as power, price and time. It is possible to adjust the power by moving the processes in less busy time intervals. The price can be reduced by introducing your own generation. For each technological process it is necessary to choose own schedule of consumption, through the established conditions of process. Generation can be used for own needs at the enterprise, it can be accumulated in capacity for the subsequent use.

Each system must be reliable in terms of consumption, so the best solution is to implement highly efficient technologies based on artificial intelligence. Such technologies will prosper in the future in the energy sector and energy management.

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